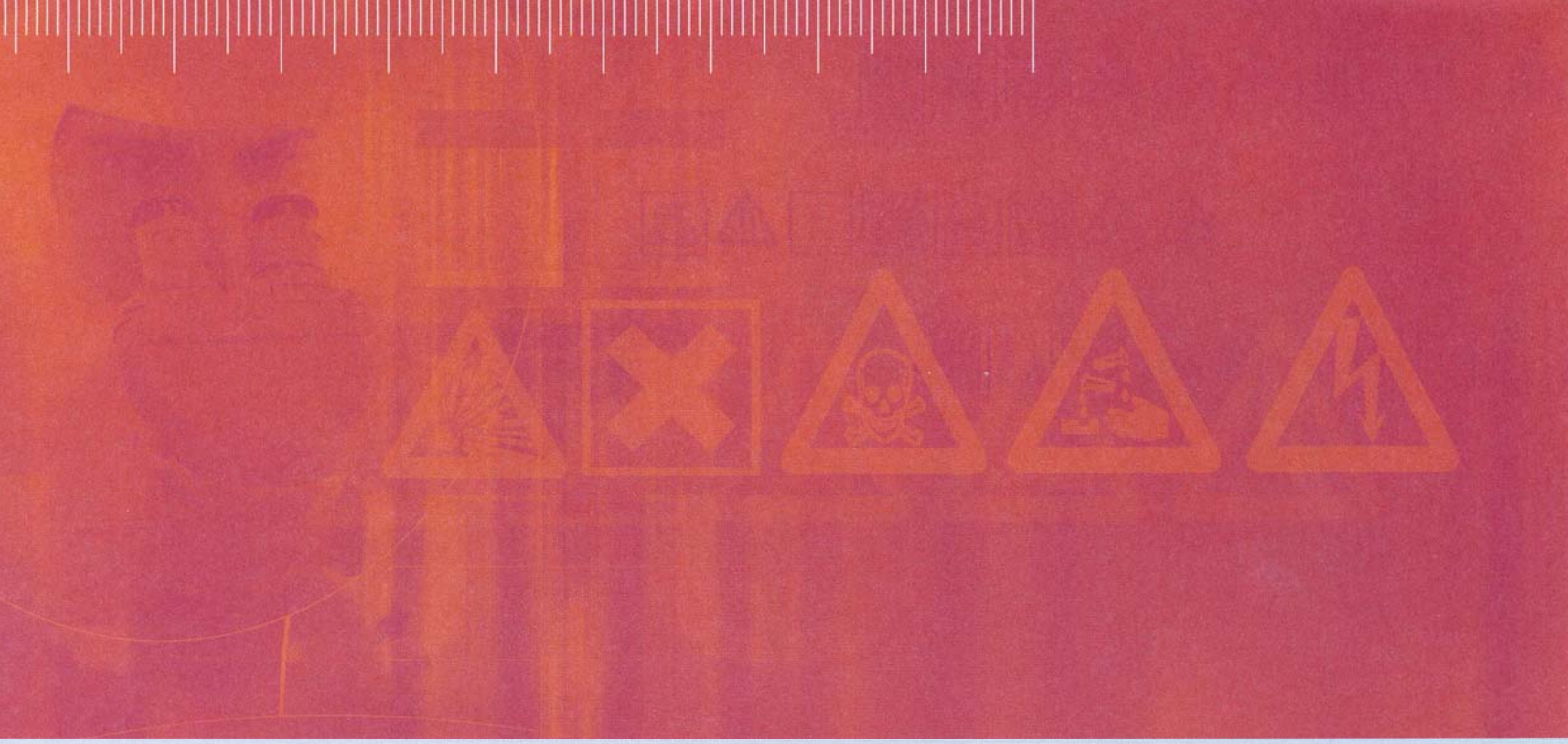

STUDY REPORT 29 / 04 /2010

DRA-09-102957-08289B

DRA71 – Operation A4 - DRA73 – Operation C2.1

Industrial installation ageing management

Refinery storage benchmark

INERIS
maîtriser le risque
pour un développement durable

DRA 71 - Operation A1.2 - DRA 73 - Operation C2.1

Industrial installation ageing management
Refinery storage benchmark

Verneuil-en-Halatte (60)

Study team: Gaëtan PROD'HOMME, Sébastien RICHOMME

FOREWORD

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The present study report written in English is for information only. The French version shall prevail over any translation.

	Written by	Reviewed by	Checked by		Approved by
Name	Gaëtan PROD’HOMME Sébastien RICHOMME	Mathieu REIMERINGER	Marie-Astrid SOENEN	Bernard PIQUETTE	Yann MACÉ
Title	Engineers Structural Resistance Unit (REST) Accidental Hazards Department	REST Unit Manager Accidental Hazards Department	Administration Support Delegate Accidental Hazards Department	Head of the Dangerous Phenomena and Structural Resistance Unit Accidental Hazards Department	Director Accidental Hazards Department
Signatures					

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1. INTRODUCTION – STUDY CONTEXT

1.1 INTRODUCTION

Considering the incidents and accidents that have occurred over the past years in French industrial installations, the French Ministry of Ecology, Energy, Sustainable Development and the Sea (MEEDDLM) launched, through a memo dated 12 December 2008[1] (see Annex A in the General Benchmark[2]), an action plan on managing ageing as part of the prevention of technological hazards.

As stated in this memo, “All equipment and installations likely to lead to a technological hazard may be covered by actions as part of this plan, whether the equipment and the installations contain hazardous or polluting products” or “whether they form a safety mechanism by their design (e.g. a firewall), whether they play a part in compensating for deviations (e.g. retention, alert or intervention systems) or whether they play a part in safety management (e.g. command and control systems). Any salient point will receive especially significant attention as part of this plan”.

Discussions took place in working groups (WGs) that gathered competent authorities, experts and industrial operators. The working group themes are listed below, the last four being dedicated to industrial installation ageing:

- flammable liquid regulations,
- pipelines,
- piping and vessels,
- electricity and instrumentation,
- storage tanks,
- civil works.

Furthermore, in its memo dated 11 February 2009[3], MEEDDAT detailed how INERIS would contribute to the action plan on managing ageing (refer to Annex B in the General Benchmark referenced as INERIS-DRA09-102957-07985C).

This report relates to the specific study of managing ageing in refinery storage. It is based on a comparison between the regulation and standards applied in France, as regards ageing management (testing and inspecting equipment, qualifying bodies to perform these inspections, etc.).

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[1] Memo BRTICP 2008-601-CBO dated 12 December 2008

[2] Cf. Report INERIS-DRA09-102957-07985C

[3] Memo BRTICP 2009-46/OA dated 11 February 2009

The information provided in this report is taken from:

- A literature review of regulatory documents, standards and professional guidelines,
- Information on practices applied as collected during visits to certain industrial operators (refineries, flammable liquids storage sites, LPG filling facilities and chemical plants),
- Exchanges with expert bodies (CETIM, French *Institut de Soudure* (Welding Institute), Bureau Veritas, etc.) and exchanges that took place during the working groups set up by the Ministry on the theme of ageing.

This report presents a fairly wide but not necessarily exhaustive panorama. Many of the sources used and practices observed in the field are highly specific to industrial sectors.

Regarding any comparison between practices in France and abroad, the reader should refer to the analysis performed in the General Benchmark mentioned above. This analysis does not highlight any aspect that is specific to refineries likely to be presented in this report.

This report, complying with the terms of INERIS' assignment, only covers pressurised or atmospheric pressure storage vessels present in refineries. These two different types of storage have, necessarily, been covered separately. The equipment studied is presented in the following paragraph, before presenting a review of accidents. The monitoring policies applied in the refineries are then detailed from a regulatory, theoretical, and then practical point of view. Lastly, all of the remarks drawn from exchanges with petrochemical industrial professionals are reported in the last chapter.

1.2 STORAGE TYPES: PRESENTATION AND MAIN CHARACTERISTICS

1.2.1 Pressure Vessels

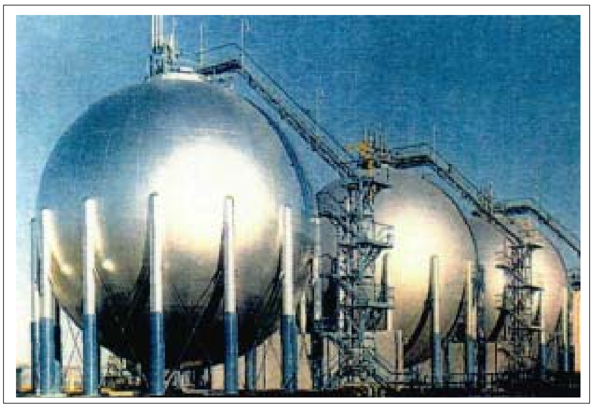
1.2.1.1 Spheres

Products such as propane and butane are stored in liquefied form under pressure in this kind of vessel in refineries.

Spherical tanks have a radius of 5 to 11 metres and a volume of 500 to 4,500 m^3.

The weight stored depends on the density of the products stored in liquefied form. For a 1000 m^3 sphere, the weight may vary from 400 tons (propane) to 700 tons (ethylene oxide).

The thickness of the shell is always in excess of 10 mm. This kind of vessel must be resistant to internal pressure levels of 8-9 bars for butane and up to 25 bars for propane.



The superficial foundations used comprise localised concrete barrels that are isolated or linked together by stringers.
They can, where necessary, be combined with deep foundations on piles.

1.2.1.2 Horizontal Vessels

This kind of cylindrical vessel may store the same products as the spheres referred to above.

Most of these vessels are 1.5 m to 3 m in diameter with a length of around 10 m, corresponding to a volume of 100 to 2,000 m^3.

The longest vessels may measure a few dozen metres in length.

Horizontal vessels are generally placed on cradles. There are also cases where they are belted down onto the cradles.

1.2.2 *Atmospheric Tanks*

Atmospheric tanks account for the vast majority of the large capacity tanks used to hold flammable liquids.

They typically have a large diameter and therefore a low height.

They are composed of a single or a double outer metal shell.

These tanks are most often:

- Metallic: their bottom, sides and roof are made of steel,
- Vertical: their axis of symmetry is a vertical axis.

The various tanks are distinguished by:

- The type and number of hoops they are made of,
- Whether or not stiffeners are used,
- Their foundations:
  - A raft foundation or a ring foundation,
  - On piles or recessed into a well,
  - Simply supported or anchored.

- Their roof which may be floating or fixed.
  - With a floating roof: light petrol, naphtha, etc.
  - With a fixed roof: Light solvents, flux, etc. The fixed roof may be supported by the shell or sometimes by both the shell and purpose-built pillars.

1.3 PRODUCTS STUDIED

In compliance with the content of the assignment letter, this report specifically covers the storage of the following products:

- For toxic products:
  - Hydrofluoric acid. Given the lead-time available, no data specific to this substance has been identified. This report does not therefore comprise any elements that are specific to monitoring this type of storage.

- For flammable liquids:
  - Petrol varieties,
  - Diesel fuels (including heating oil),
  - Ethanol.

- For liquefied flammable gasses:
  - Butane,
  - Propane.

Hydrogen sulphide is explicitly mentioned in the assignment letter and is in practice stored, as it is produced, at the production facility and not in a storage unit. Consequently, it will not be covered hereinafter.

1.4 DOCUMENT ORGANISATION

This report is organised as follows:

- Chapter 2: Accident review
- Chapter 3: Pressure equipment monitoring policies
- Chapter 4: Atmospheric tank monitoring policies
- Chapter 5: Outcomes of exchanges with petrochemical operators

2. ACCIDENT REVIEW

The following accident review was produced on the basis of BARPI records (www.aria.developpement-durable.gouv.fr).

2.1 PRESSURE EQUIPMENT (PE)

There have been few accidents caused by ageing in the pressure storage facilities found at French refineries. Only one significant accident was recorded in 2004:

- **Saint-Hervé (Côtes d'Armor) 14/06/2004**: A propane leak from a **sphere**. The vessel, dating from 1974, had been pressure tested for the last time in 2002.
  - The mechanism at fault was a lower tapping formerly used for connecting a safety level system. This tapping, not fitted with any valves and located some 2.50 metres below the top of the sphere, was made of steel.
  - A leak from a 1 mm breach was detected there during surveillance rounds.
  - After expert assessment, the breach was caused by a perforation in the tube, a few millimetres in length, in an area close to the tube junction where it is welded to the flange (at 10 mm). The perforation was 3 mm long and was caused by external corrosion due to rainwater retention. The corrosion formed a 50 mm patch along the length of the tube.
- **The leak occurred only 21 months after the regulatory inspection** of the pressure equipment. Analysis of feedback caused special attention to be paid to small tappings, in addition to the inspections imposed by regulations relating to pressure vessels.

  Corrosion had perforated a thick layer (more than 4 mm) of steel on a part exposed to the open air. This corrosion had gone undetected by inspection measures.

  Small tappings (with a low diameter) present a drawback as they are **difficult to inspect and often cannot be isolated** (no manual or automatic cut off device to easily control a leak that may be fed by the contents of the sphere).

2.2 ATMOSPHERIC STORAGE TANKS

This analysis by INERIS of feedback from past accidents does not aim to be exhaustive.

INERIS has selected a number of accidents intended to demonstrate a wide range of causes and consequences in terms of ageing-related accidents. This study highlights a number of recent accidents linked to aboveground tanks at refineries and fuel storage sites.

- **Donges Refinery, France – 29/09/1999**: Leak from a 25,000 m^3 diesel fuel tank:
  - There is no available data on the cause.
  - This incident resulted in ground pollution: excavation of 1,000 m^3 of earth and the creation of a drainage trench to prevent pollution of the canal.

- **Berre l'Etang Refinery, France – 14/10/1991**: A 30 m^3 leak of fuel oil from a tank:
  - A **valve failure** occurred on a partially buried 80 m^3 tank.
  - The leak caused ground and marsh pollution.

- **Martigues Refinery, France - 17/01/2008**: An oil leak was observed from the floating roof of a storage tank.

In addition, the following accidents exceed the scope of this study, but provide interesting information as regards ageing:

- **Mardick Refinery, France – 24/03/2008:** At a refinery, a leak occurred from the base of a 14,000 m^3 tank containing **process water**. The containment served its purpose but the liquid released Hydrogen Sulphide and Ammonia vapours.
  - **A complete inspection had been performed** in December 2006, **concluding,** after having checked the condition of the sidewalls and the bottom, that **no work** was required.

- **Ambès fuel storage site, France – 12/01/2007**: This is the only case of an instantaneous tank failure in the French petroleum industry. The tank bottom failed suddenly releasing 13,500 m^3 of crude oil into the retention area.
  - A **wave effect** led to the release of 2,000 m^3 of oil outside of the retention area.
  - According to **a 2006 inspection report, tank bottom corrosion** and thickness losses of as much as 80% had been identified.

A number of accidents having occurred elsewhere in Europe also provide additional information:

- **Kallo Refinery, Belgium – 25/10/05:** A crude oil tank opened releasing 37,000 m^3 of oil. The accident was caused by tank bottom corrosion caused by the presence of a cavity retaining water. The post-accident analysis made it possible to identify the following points:
  - The **external visual examinations** performed did not detect this anomaly.
  - **Corrosion checks**, as defined, do not always detect localised corrosion.
  - **Internal inspection** (i.e. when empty) does not always detect tank bottom deformations (in particular elastic deformations) unless the tank is completely mapped by a surveyor.
  - The **quality of the tank foundations** is of capital importance in tank base ageing.

- **Milford Haven Refinery, United Kingdom - 30/09/83:** The fire that caused the phenomena was triggered by the presence of flammable vapours over the tank roof due to the presence of cracks in the roof.
  - Given the violent winds prevailing in this coastal part of Wales, mechanical **fatigue-related cracks** had formed on the surface of the floating roof, and underwent regular repairs.
  - **When an inspection** of the roof was performed a few days prior to the accident, 28 cm long cracks and **crude oil seepage were observed** on the pontoon membrane surface.

- **Fawley Refinery, United Kingdom - 14/07/1999:** At a refinery, a 400 m^3 tank present on-site for some forty years and containing crude oil, burst and its contents escaped into the retention zone.
  - This tank had been inspected in 1991 and the steel bottom plates had been replaced.
  - The next inspection was scheduled for 2001 given that **according to the estimated corrosion rate**, **only spotting was expected** between these two inspections. The spotting was expected to cause only slight leaks, that could be controlled by injecting water into the base of the tank.
  - In actual fact, **approx. 20 cm^2 of the bottom steel was corroded** and the oil leak had soaked the tank's sand foundations **so that the tank failed far more suddenly than expected by the operator** with a rapid release of oil into the retention zone.
  - The **minimum tolerated thickness criteria** stated by the operator was in fact **lower than international standards** (0.5 mm instead of 1.25 mm or even 2.5 mm).
  - Measures taken:

- Similar tanks on-site were withdrawn from service as soon as possible and, in the meantime, the height of the water base was increased and high level tests performed.
- The facility was also to revise its inspection and rehabilitation program in compliance with the standards set out by a petro-gas industry standards body.
- The tanks will now be covered by a layer of epoxy.
- The corrosion rate calculations and minimum thickness tolerated for the metal by the operator were reviewed.

* **Essex Refinery, United Kingdom - 28/02/1999:** At a refinery, a 15.5 ton oil leak occurred from an atmospheric storage tank with a floating roof and a 100,000 ton capacity.

  This leak was probably due to tank base corrosion.

2.3 SUMMARY

The first observations resulting from this review of storage-related accidents is the low number of accidents affecting pressure vessels. Nevertheless, it is remarkable to see that the degradation affecting the sphere in the accident identified was due to a tapping. Feedback also shows the efficiency of frequent visual inspections as the leak in this case was discovered during operator rounds, meaning that it could therefore be controlled.

Regarding atmospheric storage systems, the type of product stored appears to be an important factor, as a high proportion of accidents involve crude oil. The relevant operators met during this study confirmed the fact that crude oil was a more corrosive product than refined products. This is especially due to the presence of sulphur. Further, it is clear that crudes now being refined contain increasing quantities of sulphur.

The location and kinds of degradation observed are also noteworthy. Floating roofs may foster cracks likely to lead to their collapse. The tank base and annular plate are identified as being the most sensitive points. This is because any damage to them may lead to severe leaks, as well as sudden and devastating failures.

Lastly, the accidents in Saint Hervé in 2004, Fawley in 1999 and Kallo in 2005 show that routine checks do not provide complete knowledge of the storage tank condition. This is particularly the case as it is technically impossible to check the storage tank at every one of its many points, giving rise to limits inherent to the choice of a predetermined number of locations for performing tests.

3. PRESSURE EQUIPMENT MONITORING POLICIES

This section will present in the following order:

- The theoretical aspects (general presentation of regulations, professional standards, etc.),
- Relevant data taken from the literature,
- Practices in refineries.

3.1 THEORETICAL ASPECTS

3.1.1 French Regulations

French regulations relating to pressure equipment (PE) are relatively recent. The major regulations are less than ten years old. They constitute the harmonisation of pressure equipment regulations across the European Union. **Nevertheless, the current harmonisation trend does not cover the operation and monitoring of pressure equipment.**

3.1.1.1 Texts Related to Pressure Equipment Manufacture and Setting into Service

As part of an effort to harmonise legislation aimed at facilitating the sale of pressure equipment across Europe, the two legal texts that cover the design, manufacture and conformity assessment of pressure equipment are:

- **Pressure Equipment Directive (97/23/EC) on harmonising member state legislation on pressure equipment (PED):** This directive harmonises European practice in terms of the design, construction and compliance validation for pressure equipment.
- **French Decree No. 99-1046 dated 13 December 1999 related to pressure equipment**: This is the French transcription of the European directive covering the construction and commissioning of storage facilities containing fluids under pressure exceeding 0.5 bars.

  The European Directive (PED 97/23/EC) and French Ministerial Decree (DM 13/12/99) constitute the regulatory context for designing and manufacturing pressure equipment. The prescriptions set out in these texts directly influence the quality of the equipment.

The PED as well as the guidelines/design standards define the inspections and non-destructive tests to be performed depending on the types and categories of construction/risk. The steps required for validating compliance are set out in French Ministerial Act of 21/12/99.

Equipment is organised according to the volume, service pressure and fluid group contained. There are two fluid groups:

- **<u>Group 1</u>** comprises fluids that are considered to be hazardous under the terms of Article R. 231-51 of the French Labour Code and that belong to the following categories:
    - explosives,
    - extremely flammable substances,
    - highly flammable substances,
    - flammable substances (when the max. admissible temperature exceeds the flashpoint),
    - highly toxic substances,
    - toxic substances,
    - oxidizers.

- **<u>Group 2</u>** combines all other fluids.

There are various steps for evaluating the compliance of equipment regulated by the PED and which involve approved or notified bodies:

- Non-Destructive Tests (NDT) depending on the construction category,
- A hydrostatic pressure test,
- A safety mechanism examination,
- Equipment CE marking and labelling,
- Writing instruction manuals and inspections to be performed.

The inspections required will be implemented by approved bodies in compliance with standards. The practical criteria for equipment acceptance are to be found in the design codes/standards.

The fundamental parameters for this step are the acceptation criteria applied during inspections (only in the construction codes) and the test parameters (various values provided in regulations and codes), in particular the test pressure and temperature levels.

3.1.1.2 Texts Related to In-Service Monitoring of Pressure Equipment

French Decree dated 13/12/99 sets out pressure equipment in-service monitoring requirements in general terms.

To this decree have been added various French legal texts covering in-service monitoring:

- **Amended Act of 15 March 2000 (consolidated version)**, relating to the use of pressure equipment (as amended by the Act of 13 October 2000 and by the Act of 30 March 2005): this act defines the constraints in terms of operational monitoring required for pressure equipment. The equipment groups subject to these constraints vary according to the fluid group contained, storage pressure and volume stored (or diameter for piping).

  In refineries, the fluids stored under pressure belong to group 1 and are subject to high pressures. Large volumes are therefore subject to AM 15/03/00.

  AM 15/03/00 also provides details on certain safety characteristics to be complied with during the design stage.

  Pressure equipment monitoring comprises two fundamental regulatory aspects (detailed in subsection 3.2.3.3):

  - Periodic inspection,
  - Periodic requalification.

- **Ministerial decree T/P 32510**: “Recognition of an industrial establishment’s inspection department”. This decree offers operators the possibility of defining their own inspection plans subject to organisational restrictions and the use of professional guidelines by the Recognised Inspection Department. For the petrochemical industry the guidelines that are applied are UFIP/UIC DT 32 and DT 84.

- **BSEI circulars**:
  - 06-080: Application conditions of AM 15/03/2000,
  - 05-139: Approval of guideline DT 32,
  - 06-194: Approval of guideline DT 84,
  - 07-107: Periodic Requalification exemptions, referral to the AFIAP guideline.

- **“Interpretation Forms”**: Answers to questions related to the application of AM 15/03/00.

In terms of equipment monitoring, all of the texts provide regulatory parameters affecting ageing during design, manufacture, setting into service and alteration. These parameters are highlighted in the following chapters.

All of the regulatory texts offer two possible pressure equipment monitoring policies, which are not mutually exclusive:

- Monitoring (see 3.1.4.2) in compliance with the conditions set out by AM 15/03/00,
- Monitoring by a Recognised Inspection Department (RID) (see 3.1.5.1), in compliance with the conditions defined by the accepted professional guidelines.

French refineries all have a Recognised Inspection Department.

3.1.2 Standards and Design Codes

The European directive ensures compliance with a number of criteria as regards the design, manufacture and setting into service of pressure equipment.

Manufacturers are required to demonstrate the validity of their products. They may base this on manufacturing codes.

Naturally only regulations are mandatory (PED 97/23/EC); codes or standards are not. On the other hand, so called “harmonised” standards (e.g. EN 13445) benefit from an “assumption of compliance” with regulations. All equipment that is supposed to meet these standards is reputed to be compliant with the PED.

National codes may also serve as a reference. In France, CODAP is considered complaint with the demands of European regulations.

The standards and codes most often used in France for construction are:

- CODAP: “CODe de construction des Appareils à Pression” (Pressure equipment construction code) (France),
- EN13445: “Unfired pressure vessels” (“harmonised” European standard),
- ASME VIII: “Boiler & Pressure Vessel Code VIII/Div.1” (United States),
- BS 5500: “Specification for unfired fusion welded pressure vessels” (Great Britain).

The version of the code used is important as the codes evolve on the basis of feedback and changes in techniques.

From these texts, certain parameters that influence vessel ageing and that depend on the ordering party can be mentioned:

- Construction category: This takes into account the product stored, the volume and the operating pressure. This may be overestimated to increase the safety margin.

- The choice of design loads: Foreseeable service loads (pressure, etc.), conventional loads (wind, snow, etc.) and exceptional loads (earthquake, fire, etc.).
- The safety margins in the calculation: Safety factor, extra corrosion thickness, choice of materials, choice of internal and external coatings, etc.
- Manufacturing parameters: Quality of assembly, welding, choice of materials, manufacturing tolerances, etc.

3.1.3 Inspection Standard EN 12819

This standard does not appear to be used in refineries. Nevertheless it provides information that is of interest on pressure equipment containing LPG.

Standard EN 12819 on “Inspection and requalification of LPG tanks greater than 13 m^3 overground” (12/2002), currently under revision, provides practical elements for inspecting pressure equipment containing butane or propane.

This is a standard that covers the methods and context required for inspecting LPG tanks. The standardisation commission that introduced this standard comprises known gas operators and professional bodies such as SNCT (Société Nationale de la Chaudronnerie et de la Tuyauterie) or CFBP (Comité Français du Butane et du Propane). This standard includes the following information:

- The interval between two requalifications is 12 years at most and depends on:
  - Design specifications,
  - The corrosion protection system,
  - The LPG quality control system,
  - The degree of control over tank filling and maintenance.
- Routine inspection consists of a visual external examination and at least eight specific inspection points.
- Periodic inspection **(for which no frequency is set)** consists of an external examination and six specific checks.
- Requalification is a periodic inspection to which are added four checks and an inspection to be chosen from among:
  - An internal visual inspection,
  - A hydraulic test,
  - An acoustic check,
  - A thickness check,
  - Another equivalent method.

Note: In a similar way, standard EN 12817 exists for tanks with a capacity of less than 13 m^3.

3.1.4 Inspection Bodies

3.1.4.1 Recognised Inspection Department

This report relates to refinery storage. These installations have their own Recognised Inspection Department.

In France, inspection services are recognised by the Prefect via criteria set out in DM T/P 32510. The latter is presented in the General Benchmark report in Annex E.

In substance, the following points should be retained:

- Criteria that trigger a strong degree of management involvement in inspection work and in the setting up of the department, the independence of the Inspection Department and a minimum level of expertise and authority (based on standard EN ISO/IEC 17020).

Recognition/expertise:

- There is no formal approval process for the inspectors who perform the periodic inspections (Art. 10 BSEI 06-080).
- There are training courses and inspector certifications, notably those provided by industrial bodies such as UFIP or UIC. Trainers are certified by COFRAC (COmité FRançais d'Accréditation) or equivalent.
- Recognition is established following a DRIRE audit that is renewable every three years on the basis of an audit.
- Initial recognition is followed by regular checks by DRIRE.

Field of activity:

- A RID must perform the inspection plan in accordance with applicable guidelines.
- A RID may perform pressure equipment periodic tests and inspections.
- A RID is not intended to perform periodic requalification, this is performed by an approved body.

  Nevertheless, a RID may be empowered to do this under certain conditions (see Q/A forms DGAP5/3 in DMTP 32140).

  The same applies for the setting-into-service tests and post-servicing checks.

3.1.4.2 *Other Bodies*

The sites studied, although they have their own RID, call on external inspection bodies. The main assignments conducted by external bodies are tests, inspections, setting into service and periodic requalification.

Depending on the assignments contracted to them, these bodies must be recognised by COFRAC which provides accreditations for certifying bodies, or COFREND (COnfédération FRançaise pour les essais Non Destructifs).

The only bodies that are approved for performing pressure equipment periodic requalifications are so-called approved bodies: APAVE, ASAP (Association regroupant Institut de Soudure, NORISKO, SGS and SOCOTEC) and Bureau Veritas (Act of 22/06/05).

Approval is granted by the Ministry following consultation with the Commission Centrale des Appareils à Pression (CCAP) (Central Commission for Pressure Equipment) and subject to:

- Receiving COFRAC approval,
- Carrying insurance cover,
- Providing minimal territorial coverage,
- Having a sufficient volume of business,
- Taking part in writing standards,
- Being inspected by DRIRE.

3.1.5 Guidelines

Given the abundance of texts covering pressure equipment, INERIS chose to study the guidelines presented in the table hereafter. These guidelines are those most often used at refining facilities. Nevertheless, this list does not claim to be exhaustive, simply representative.

Guidelines	Reference	Recognition mode
RBI method guideline	API 580 API 581	-
FFS method guideline	API 579	-
Inspection plan guidelines	UFIP/UIC guideline DT 32 Guide UFIP/UIC guideline DT 84	App. by BSEI 05-139 App. by BSEI 06-194
Non-French guideline for inspecting pressure vessels	API 510	-
Inspection choice guideline	UFIP/UIC guideline DT 75	Reference DT 84
Regulation waiver guidelines	AQUAP “insulation” AFIAP “acoustic emission”	App. by BSEI 07-107
Repairs guideline	AQUAP “repairs”	-

These guidelines are presented below and then briefly summarised in Annex A of this report. The practical data, in the general sense of the term, was then extracted so as to be highlighted and compared.

3.2 RELEVANT DATA FROM THE LITERATURE

3.2.1 Degradation Mechanisms

Based on the AQUAP “Regulatory inspection of pressure equipment with an outside or inside coating” presented above, the following points qualified as risk areas can be identified:

- Areas that may be affected by corrosion or cracking of thermal, mechanical or chemical origin,
- Complex welds or significant stress concentration points such as:
  - Heterogeneous welds,
  - Angular hoop-cone link welds without overlap,
  - Tappings with a diameter in excess of 50% of the equipment diameter,
  - Tangential or oblique tappings,
  - Welding nodes close to stressed areas,

- **Tappings** subject to **cyclic** or specific stresses such as:
  - Generator valve seats,
  - Feeder or extraction piping,
  - Tubes for linking to a rotating machine (compressor, agitator, etc.),
- **Supports or mounting points** where vibration or fatigue cycles occur,
- **Tubing bases** likely to be exposed to fluid leaks, especially in the case of corrosive fluids (e.g. filling tubes, etc.).

In the same way, representative equipment points are indicated, such as:

- The lower generator and low points of horizontal tanks,
- The base and head cover of upright equipment, especially around the head and base piping,
- Representative sections of **circular and longitudinal seals** including the corresponding **welding nodes**,
- Representative parts of reinforced binding bands for equipment operating in a vacuum,
- Representative parts of insulation support crowns, where these are directly welded onto the shell.

Note that the degradation mechanisms for LPG storage appliances are mainly faced with “external” issues, especially the external tappings and pipes where most of the degradation is located.

3.2.2 Non-Destructive Testing (NDT)

Non-destructive tests can be performed in different ways, which are covered by standards and certifications (see General Benchmark). The common methods are presented here:

- **Visual examination** (*testing the overall appearance):* Compliance with dimensions and the macroscopic condition of the surfaces is observed with the naked eye or using magnifying glass type instruments. This is the “*simplest*” inspection. It does however require a very extensive knowledge of the equipment in order to be effective.

- **Dye-penetrant examination** (*surface quality testing):* A penetrating liquid is applied to the surface then it is cleaned off. A developer is applied then to highlight any discontinuities at the surface (where the liquid penetrated).**Magnetic-particle inspection** (*surface quality testing):* A ferromagnetic powder is applied to the surface to be tested before subjecting it to a magnetic field. Emerging, plugged or underlying surface defects are highlighted by the appearance of a leakage field.
- **ACFM (Alternative Current Field Measurement)** (*weld and surface testing*): Applying an alternating current to the tested surface causes an induced magnetic field. This shows up distortions in the presence of cracks or faults with openings. This method is also known as eddy current testing.
- **Radiography** (*internal examination*): The structure's compactness is tested using X-rays. Internal flaws such as bubbles, porosities or internal cracking are revealed in this way.
- **Ultrasonics method** (*an internal examination and thickness measurement*): Very high frequency (ultrasonic) waves are transmitted to the structure and their reflection in the material is analysed. Internal defects are highlighted by a modified reflection and by wave diffraction.
- **Acoustic emissions method** (*an internal examination and thickness measurement*): The structure is "listened to" at the time when it is loaded (i.e.: placed under pressure). Evolving defects (evolving cracks, local plastic deformation, etc.) generate acoustic emissions that make it possible to localise and qualify the issue.
- **Sealing testing** (*setting into service, specific testing*): Performed in compliance with various methods (15 are recorded in CODAP), this test is used to highlight the presence of faults that alter structure sealing. These tests are performed using a tracer gas to detect leaks.

3.2.3 Inspection

3.2.3.1 Inspection Plan Purpose and Content

DM T/P 32510 describes the inspection plan as follows:
"A document that defines all of the operations prescribed by the Inspection Department to manage the condition and compliance in time of pressure equipment or a group of pressure equipment devices being monitored".

The Inspection Plan (IP) provides the basis for organising inspections and testing of all of the pressure equipment covered by AM 15/03/00 and present in the refinery.

It is up to the RID to write an Inspection Plan based on UFIP guideline DT 32 or DT 84.

The aim is to **take into account a maximum number of parameters that affect equipment integrity** so as to best adapt the quality and quantity of monitoring operations. As a result, the RID can adapt the frequency and type of regulation inspections for all pressure equipment under its responsibility.

Once the RID has gained approval from DREAL and has applied UFIP/UIC guideline DT 84, then the inspection plan must especially state or justify:

- Tank characteristics,
- **Degradation mechanisms** that may affect the equipment,
- The occurrence probability and level of consequences of any failure, which results in criticality,
- The **description of inspection actions** (periodicity, type, implementation conditions and localization) whether they are regulation or monitoring actions,
- The **Critical Operating Condition Limits** (COCL) for the equipment and the related monitoring methods.

3.2.3.2 Plan Implementation Methods

Here the aim is not to go into the complex details of creating inspection plans, but rather to present the noteworthy steps involved. These steps are based on the way the RBI method works. The general principle of this method is restated in the UFIP/UIC guidelines used in France.

The steps for producing an inspection plan in accordance with the RBI method are as follows:

- **Planning** the actions to be performed.
- **Selecting** the equipment and the **group**.

  Here the UFIP and UIC guidelines include the iso-degradation loop concept. This makes it possible to group equipment by type of degradation. This notion is especially important for piping.
- **Collecting data** on all equipment.

  Here the aim is to study feedback, results from inspections performed, safety policies, etc.
- Identifying degradation mechanisms and equipment failures.
- Determining the probability of a failure linked to each degradation mechanism.

  This calculation is presented in the form of a weighting based on an initial equipment-related probability. The environment, the product contained, the feedback and the knowledge of the equipment are the source of these weightings.
- Determining the consequences of any failure linked to each degradation mechanism.

This calculation takes the form of weighting based on an initial equipment-related value, the environment, the product contained and feedback.

- Evaluating risks using a criticality calculation.

  The aim is to couple the failure probability with the degree of consequence for each degradation mechanism.

- **Minimising the risk** by integrating inspections into the life cycle.

  The failure probability is minimised according to the degree of knowledge of the equipment condition and therefore according to the number and type of NDT performed. This step involves drafting a "practical" inspection plan, i.e. setting inspection dates.

  This is a critical step as it constitutes the direct consequence of inspections on equipment criticality.

- **Integrating** activities leading to **risk reduction** (i.e. the safety policy).

- Reassessing and updating the risks involved.

  If the risk level is too high, the inspection plan is reviewed.

- Defining roles, responsibilities, training and qualifications for every player according to the necessary actions identified.

  This is also a fundamental stage.

<u>Note:</u> With the RBI method, the actions to be undertaken are pre-scheduled and are included in the risk evaluation. With other approaches, the inspection plans are defined by the criticality.

3.2.3.3 Inspection Methods

French regulations on pressure equipment, especially AM 15/03/00, regulate the monitoring of the pressure equipment covered. Given the volumes stored and pressures that apply to LPG tanks at refineries, such equipment is covered by this act.

At refineries, in France, regulatory monitoring measures are coordinated by the refinery's Recognised Inspection Department. The fundamental monitoring principles are the same as for facilities that do not have an RID. Nevertheless, implementing advanced monitoring methods (like RBIs) allow RIDs to modulate the various regulation inspections.

The inspections relating to monitoring pressure equipment at refineries may be characterised as follows:

- **<u>In-service monitoring</u>**:
  - **Routine checks: not regulated**, these involve the use of visual examinations to monitor the external behaviour of the structure, especially prior to every filling operation.

- **Additional checks: left to the operator's discretion** so as to check that these installations are operating correctly. The RIDs schedule the tests required to extending the out-of-service inspection interval. These are included in the inspection plan and defined according to degradation mechanisms and specific points known for the equipment. The results of these checks are added to the equipment's technical record.

- **<u>Out-of-service monitoring</u>**:
  - **Periodic Inspection (PI): Regulated**, this inspection involves checking that the state of the equipment meets the safety conditions required for its operation.

    The NDTs to be performed are defined by skilled inspectors according to the mandatory inspections as determined by AM 15/03/00. The recipient must be stripped and any removable elements must be disassembled to perform the following inspections:

    - **An external examination,**
    - **An examination of safety devices,**
    - **An examination of devices under pressure.**

  Important note: The internal examination is not required for butane and propane tanks. "This concession is justified by the fact that the characteristics of the products involved are set by regulation and that long years of experience have shown not only that they are innocuous but that they also have a protective effect on the metals with which they come into contact" BSEI 06-080.

  Inspections take into account:

    - **Degradations observed,**
    - **Recommendations set out in the equipment instruction manual.**
    - **Forecast operating conditions.**

  The criteria must feature in the construction guidelines.

  For refineries with an RID, the periodic inspection frequency is set by the inspection plan produced from the professional guidelines (UFIP/UIC guidelines). These also enable the methods used and inspections performed to be adapted.

  For LPG storage facilities, there are two European standards currently under revision that provide indications on the elements to be checked (EN 12817 and EN 12819). They do not appear to be used at the refineries studied.

  These PI operations are intended to "verify that the condition of the equipment allows it to be maintained in service with a level of safety compatible with forecast operating conditions" as set out in AM 15/03/00. This operation, performed by a skilled person (from the facility, facility RID, or an external approved body) under the Operator's responsibility, leads to a detailed and signed report. Additional investigations may be made if necessary.

- **Periodic requalification (PR):** Regulated, requalification comprises performing the periodic inspection on the equipment and its devices as well as a hydraulic pressure test. The checks to be performed are presented in AM 15/03/00:
  - **A complete inspection (similar to the periodic inspection with a further examination of the safety devices),**
  - **An examination of documents (description records and the records kept during operation),**
  - **A hydraulic test:**
    - A method comparable to the test performed when assessing compliance during setting into service,
    - The test criteria are also similar, the test pressure may be changed if the operational conditions warrant this,
    - The test conditions are defined in AM 15/03/00,
    - The test is run on the tank and on its related pressure equipment.

  Requalification is generally performed with the equipment out of service.

  It is performed by an expert from an approved body or from the RID if they are specially qualified for this purpose (refer to 3.1.4.2). Requalification leads to the issue of a written certificate signed by the expert and sent to the operator. Successful requalification results in recipients receiving the “horse head” sign and the date of the hydraulic test or periodic requalification (if no hydraulic test was performed).

A number of terms in relation to the PI and PR requirements are set out in UFIP guidelines DT32 and DT84. The most significant terms are:

- Regulation frequencies applicable in France may be extended. This condition is expanded on in the next paragraph and has the advantage of allowing regulation checks to coincide with refinery shutdown periods.
- For some devices, the hydraulic test may be replaced with a hydrostatic or pneumatic test with an acoustic emissions test. The conditions for performing these tests are presented in the AFIAP guideline recommended by the administration in BSEI 07-107. The latter also states which pressure equipment is subject to this waiver. In addition to these devices, it is possible to apply to replace the hydraulic test on a device by contacting CCAP.

  In all cases, the replacement of a hydraulic test with a pressure test must be justified by the RID to DRIRE who are free to reject the application.
- Subsection 3.2.3.6 in this document details the insulation removal conditions applicable during inspections and periodic requalifications as well as the specific measures that may be retained for one or two "baseline" items of equipment that are representative of a set of similar equipment.

- As part of the monitoring actions called for in the inspection plan, the RID may perform a more complete inspection, test or examination of one or more reference items of equipment. These may partially or completely replace the inspections, examinations and tests of the same type that were to be undertaken on similar equipment devices.

  The one or more reference equipment items chosen by the RID are most often those most affected by any damage that may occur. Their choice is justified and is recorded in the one or more inspection plans for the equipment in the relevant assembly.

3.2.3.4 Inspection Frequencies

AM 15/03/00 recommends performing periodic inspections and requalifications at regular intervals. Consequently, the following frequencies are found in the act:

- PI takes place at least every 40 months.
- PR is to take place every:
  - Three years for fluids containing corrosive impurities such as hydrogen sulphide in oil,
  - Five years for fluids that are toxic, highly toxic or corrosive for the tank walls,
  - Ten years for other fluids.

Guideline DT 32 allows the RID to extend PI intervals to 5 years (60 months) and PR intervals to 10 years. This is a simplified version of guideline DT 84.

Guideline DT 84, applicable only to RIDs recognised for more than five years, allows the RID to extend PI intervals to 6 years (72 months) and PR intervals to 12 years.

In accordance with these guidelines, a detailed study of degradation mechanisms, criticality aspects and operating conditions should be conducted. This leads to the production of the inspection plan (IP).

This guideline allows the RID to adapt inspection and requalification terms (see 3.2.3.3) by applying an approach that takes measured risk into account. The guideline provides prescriptions on the elements to be taken into account while leaving the RID free to determine the practical application.

All of the approach results are given in the IP. Furthermore, the guideline includes the feedback context where lessons are to be included in the IP. This guideline is the result of the petroleum industry implementing the RBI method. It constitutes a guiding principle that must be implemented by every industrial operator with an RID, using its own standards (in particular for calculating the criticality and for setting out detailed inspection plans).

	AM 15/03/00	DT 32	DT 84
Maximum periodic inspection frequency	40 months	5 years	6 years
Periodic requalification frequency	3, 5 or 10 years	10 years	12 years

Note: For LPG, the requalification frequency defined by AM 15/03/00 is ten years.

3.2.3.5 Parallel with API Standards 510, 580 and 581

Inspections are broken down differently in API standard 510, intended for monitoring pressure equipment and not mentioned in French regulations. They do however serve as a reference in UFIP/UIC guidelines DT 32 and DT 84.

This standard provides two monitoring steps:

- An external check performed at least every five years together with wall thickness tests at an unspecified frequency.
- An external check combined with an internal check or an on-stream inspection. The frequency of this inspection is every 10 years at most.

  This value may be reduced if the equipment's remaining service life is less than 20 years. In this case, this value is halved to obtain the maximum inspection frequency. The remaining service life constitutes the difference between the thickness measured and the minimum design thickness divided by the corrosion ratio.

The principle of the checks is set out below:

- **An external check** comprises a visual inspection covering the entire device.
- **An internal inspection** comprises a complete visit of the equipment when it is out of service. The internal corrosion level is evaluated; the measured thickness and the equipment's remaining service life may be calculated. The visit may also be the opportunity for revising the interval between two internal visits.

  An alternative method may be used to calculate the interval between two internal checks. The standard recommends calculating the maximum admissible pressure using a calculation program that complies with the ASME design code (see 0). The thickness used in the calculation is the thickness measured during the last internal visit, minus twice the thickness loss between this time and the next inspection (based on the current corrosion rate).

- The internal inspection may be replaced by an **on-stream inspection** when internal access is impossible. Nevertheless, if access is possible, replacement can be performed on condition that the following conditions are met:
    - The recorded corrosion rate is less than 0.125 mm per year,
    - The calculated remaining service life exceeds ten years,
    - The corrosive nature of the product and its components in the recipient (including traces) has been known for at least five years,
    - The external visit does not detect any problems,
    - The recipient operates at a temperature that is less than the material's failure temperature,
    - The recipient is not subject to cracking or damage caused by hydrogen,
    - The recipient has not been temporarily reinforced in any way whatsoever (patch, etc.).

  The on-stream inspection must allow all of the equipment's sensitive points to be tested using the appropriate NDT.
- **A hydraulic test** in only recommended where work is required and may possibly be replaced by an NDT.

In the API standard, the RBI is widely recommended but is not mandatory and its use implies that there is no limit to the intervals between inspections. These intervals are determined by the method.

API standard 581 is a collection of procedures for fully applying inspection management on the basis of petroleum industry equipment criticality (RBI). In particular, the equipment criticality calculation, the method's central element, is determined for each type of equipment and for every degradation mechanism. For further details, refer to the General Benchmark annex.

	API 510
External check	5 years and no set limit if RBI
External and internal check and on-stream test.	10 years max. or half of the remaining service life and no set limit if RBI

3.2.3.6 Special Cases of Insulated Equipment

Articles 11 and 24 (first section) in AM 15/03/2000 state that the periodic inspection and the periodic requalification inspection comprise an external inspection that covers all of the visible parts after stripping and removing all removable elements.

The aim is that the pressure equipment may be presented for periodic inspection or periodic requalification inspection under conditions that make it possible to check for the absence of any outside degradation. Generally, the presence of a simple coat of paint does not interfere with this inspection. This is not the case for insulation.

For insulated equipment, this measure may sometimes be suitable given the technical difficulties involved in completely removing any insulation.

In particular, the RID may adapt the insulation removal conditions according to the terms set out in an Annex that is common to both guidelines DT 32 and DT 84.

- "*Total or partial insulation removal waivers apply when external checks are performed during periodic inspections and requalifications, subject to the following points being met:*
- *The insulation is chemically neutral to the protected sidewall or its protective paint, with the evidence provided being found in the equipment file,*
- *The insulation's mechanical resistance must be suited to the operating conditions,*
- *The equipment involved is subject to regular monitoring, according to an inspection plan, confirming that the insulation is properly resistant, as attested to in the inspection reports,*
- *The equipment's operating conditions or the conditions for maintaining it when out of service cannot lead to equipment degradation, especially due to sidewall condensation under the insulation,*
- *The maintenance actions performed, especially those requested by the inspection service, ensuring that the insulation remains in compliance,*
- *Any opportunity to partially or totally remove insulation must be used to ensure an external inspection of the stripped part and to produce an inspection report.*"

Any insulation whose type, quality or specificity is poorly known must receive more attention. Specific points will need to be inspected to validate any waiver of the need to strip the insulation.

In this case and when there is any doubt over certain aspects of the insulation, the guideline recommends paying special attention to the following risk areas:

- "*Retention areas, insulation exit areas (drains, purges, etc.),*
- *Mounting points for equipment subject to vibration or to fatigue cycles,*
- *Areas liable to be affected by corrosion or cracking of mechanical or thermal origin,*
- *Expansion bellows,*
- *Complex welds or welds that may constitute stress concentration points,*

- *Disparate welds, significant or specific tappings*."

As for periodic requalification, it is acceptable to only a partially remove insulation, restricted to:

- "*The above-mentioned risk areas,*
- *Parts of the lower generating side, low points in general and bases,*
- *Representative sections with circular and longitudinal welded seams, including welding nodes,*
- *Representative parts with reinforcements for vacuum equipment,*
- *Representative parts of insulation mounting crowns, where the latter are directly welded onto the shell*".

All of the areas inspected according to these conditions must be defined in the inspection plan. Furthermore, the inspection plan must comprise the data used to validate these terms, including thickness measurements and NDT performed to this end.

Note that "*pressure equipment outer walls must be completely stripped during every other periodic requalification, starting with the fourth requalification, except if they can benefit from the reference equipment concept described hereinafter*".

The specific measures linked to families of similar equipment are set out below.

"For a set of similar equipment, i.e. similarly designed and manufactured (same materials, identical or similar manufacturing processes), operated under the same conditions, fuller investigations undertaken on related equipments taken as "reference equipment" may replace the operations that should have been undertaken on each of these items.

The reference equipment must be the equipment which would be the primary target if any damage were to occur. It is chosen by the RID in agreement with the operator.

During periodic inspections or requalifications, the insulation is removed from the benchmark equipment in accordance with the measures set out in sections 3 and 4 above. Stripping of the insulation from the other equipment is not required.

If however the checks performed on the benchmark equipment do not provide evidence that certain parts of the walls of other pressure equipments are in good condition, insulation is removed these equipments so as to perform the same checks."

3.2.4 Special Cases of Accessories

3.2.4.1 Regulations

The first article of the European Pressure Equipment Directive (97/23/EC) makes a distinction between two categories of devices: safety accessories and pressure accessories.

Safety accessories are defined as mechanisms for protecting the pressure equipment from exceeding admissible limits. These measures comprise:

- Measures for directly limiting the pressure, such as safety valves, rupture disc devices, buckling rods, controlled safety mechanisms, etc.
- Limiting mechanisms that apply intervention systems or that lead to cut-off or locking, such as switches triggered by fluid pressure, temperature or level and mechanisms for "*safety related measurement control and regulation devices."*

Pressure accessories are mechanisms that play an operational role and that have pressure-bearing housings.

In PED Annex I, a paragraph is devoted to essential requirements for safety devices.

It states that said devices must:

- Be designed and built so as to be reliable and suited to the service conditions as planned and with allowance made, where applicable, for demands in terms of mechanism maintenance and testing,
- Be independent of other functions unless their safety function cannot be impacted by other functions,
- Follow appropriate design principles so as to achieve suitable and reliable protection. These principles include positive safety, redundancy, diversity and self-testing.

The pressure limiting mechanisms (PED, Annex I par. 2.11.2) must be designed so that the pressure level will not permanently exceed the maximum allowable pressure level PS. A short duration excess pressure level is however allowed, in line where appropriate, with the stipulations set out in point 7.3.

The mechanisms for temperature surveillance and limiting (PED, Annex I par. 2.11.3) must have an adequate reaction time for safety reasons and that is compatible with the measurement function.

The Act of 15 March 2000, states in:

- Article 3

  "*Some measures in this act apply to pressurised devices installed on pressure equipment mentioned in Article 2 above. To apply these measures, the pressurised devices must comply with the measures applicable to piping or to vessels.*

  However, in the latter case, the pressurised devices that have a PS.V value less than or equal to 1,600 bar.l or with an allowable pressure level PS that does not exceed 16 bars are waived the test stipulation during periodic requalification."

- Article 6 (point 5)

  “*Safety devices must be sized to meet service conditions and the industrial processes implemented in the pressure equipment that they protect.*

  The technology retained for these devices as well as their position in the installations must be compatible with the products contained in the pressure equipment that they protect. They must especially not be damaged by toxic, corrosive or flammable products.

  The necessary measures must be taken so that any fluid release that may be caused by their operation will not present any danger.

  The conditions of their installation must not represent an obstacle to their operation nor to monitoring or maintaining them.”

- Article 11

  “*The periodic inspection comprises: An external inspection, an examination of the safety devices and additional investigations as necessary*.”

- Article 23

  “*Periodic requalification covers the pressure equipment itself and any safety devices and pressurised devices associated with it. It generally requires the relevant equipment to be shut down.*

  […]

  The need for hydraulic testing is however waived for piping, its safety and pressurised devices as well as recipients containing fluids other than water steam or superheated water with a maximum admissible or maximum in-service pressure level of 4 bars.”

- Article 26

  “*Inspecting safety devices comprises the following operations:*
    a) Inspection in accordance with the descriptive statements or pressure equipment instructions showing that the safety devices present are the original devices, or ensure at least equivalent pressure equipment protection,
    b) Implementation, in accordance with the industrial process and the fluids used, of a control on the condition of the functional elements of any safety devices or a suitable ***manoeuvrability test*** *showing that they are able to perform their function with a degree of safety that is compatible with the expected operating conditions,*
    c) Verification of the absence of any obstacles likely to interfere with their operation,

d) *For pressure equipment with a maximum admissible pressure level in bars multiplied by the water volume in litres in excess of 3,000 bar.l, recalibration of the safety valves or their replacement with a safety device that affords the same protection. The maximum admissible pressure level refers also to the maximum in-service pressure level or the boiler pressure."*

- Article 30 Notable intervention

"*Notable intervention relates only to work on one or more safety or pressure accessories without it affecting pressurised parts of the pressure equipment or the entire assembly protected by the equipment. The aforementioned check does not have to include the final examination and the test called for in points 3.2.1 and 3.2.2 respectively in Annex 1 to the Decree dated 13 December 1999 and referenced above.*"

3.2.4.2 Standard EN 12819

Standard EN 12819: "Inspection and requalification of LPG tanks greater than 13 m^3 overground" dated December 2002, specifies which devices are to be checked, in the widest sense.

It determines during which operations (routine operations, periodic inspection, periodic requalification) these devices are to be checked (see Standards for further details).

Accessories to be checked	Type of check
Valve protection cover	General condition Manoeuvrability test (where possible)
Earthing	Visual inspection of the equipotential link. Control of the condition of the connection terminal for the "vehicle" connection to the equipotential link.
Safety valve	Start opening test. For an external valve, control of spring condition. Control of drain openings. Vent tube corrosion condition (presence of protective caps). Control of valve manifold condition.
Pressure gauges	Check with a test gauge.

Accessories to be checked	Type of check
Level indicators or gauges	Check the indicators or gauges during filling with opening up to the open air.
Shut-off valves	Check for correct operation
Safety cocks	Flow limiter and non-return valve manoeuvrability.
Gaskets	If a joint is opened, seals must be replaced.
Pressure switches	Test for proper operation using a calibrated pressure gauge.
Temperature gauges	Test with a calibrated instrument.
Remotely operated valves	Test for proper response when remotely actuated.

3.2.4.3 UFIP/UIC and API Standards

UFIP DT 32 and DT 84 guidelines show agreement on regulations and specify two steps to be performed during the periodic requalification:

> "*- Examination of safety devices,*
>
> *- Inspection of pressurised devices in accordance with measures comparable to those of the equipment to which they are attached (generator, recipient, piping) or specific to the family of devices (e.g. valves, levels).*"

API 510 states that for "overpressure" safety equipment (valves, vents) where the inspection is not covered by the RBI method, valves should be tested or vents should be inspected at least every five years. In cases where the service fluid is non-corrosive, this frequency may be ten years.

3.3 REFINERY PRACTICES

A summary of the visits made to refineries is provided in Annex B to this report. The elements in this summary are described below, constituting the conclusions of the field study.

First of all, it is important to note the response made by operators of **pressurised storage vessels containing butane or propane as to the fact that this type of storage is not subject to internal corrosion.**

It should be noted that this fact is corroborated by the accident data presented previously which does not mention any accidents in France, except for the accident at Saint Hervé, which, we recall, was due to a tapping.

Generally, operators apply the RBI method for these types of storage.

RBI method mechanisms differ for each operator. Generally linked to industrial group culture, this method is applied and interpreted differently depending on the operator. The foundations (criticality principle, the way the various parameters are taken into account) are similar and comply with DT 84, nevertheless, the implementation and interpretation approaches differ. This line of thought is expanded on in the General Benchmark and in Annex A to this report.

The profession uses its own practical guidelines. Generally based on the work undertaken by an industrial group, these guidelines relate to the RBI method, the checks to be performed according to equipment and the interpretation of the results. Nevertheless, **the DT 84, API 581 and API 579 standards form a common basis** for the work by the operators. Every “group guideline” constitutes an adaptation of these general methods.

In the same way, **every facility adapts these methods** to its own issues. Despite the quality and the number of parameters used, the RBI method only takes on its full significance when it is weighted by the difficulties that are specific to each facility.

The RBI method, in the light of the test results, especially those relating to the loss of thickness, **cannot be fully applied for this kind of storage** because of the result obtained in terms of inspection frequencies which are out of all proportion in comparison with the regulation frequencies for periodic inspections and requalifications. This method allows the higher values of the frequencies set in said regulation inspections to be reached. This remark is true for all operators, regardless of the RBI method applied.

As a result, periodic inspections and requalifications are performed every 5 and 10 years (if RID 5/10) or every 6 and 12 years (if RID 6/12). Additional checks are performed on these occasions.

In terms of the actual implementation of these checks, a number of remarks were recorded during the meetings:

- Visual examination is the most effective for detecting anomalies.
- An internal visit may be performed but it is not mandatory in the regulations. Methods using sounding tools may also be used.
- “Tapping” type elements and widely speaking, elements that are hard to inspect must receive special attention.

4. FLAMMABLE LIQUID ATMOSPHERIC STORAGE TANK MONITORING POLICIES

This section will present in the following order:

- Theoretical aspects (a general presentation of regulations, professional standards, etc.),
- Relevant data taken from the literature,
- Practice in refineries.

4.1 THEORETICAL ASPECTS

4.1.1 French Regulations

French regulations covering atmospheric storage tanks containing hydrocarbons are based on the following texts: Ministerial Acts dated 9 November 1972 and 19 November 1975: “Developing and operating liquid hydrocarbon storage sites” and the Ministerial Act dated 4 September 1967: “Developing and operating plants for treating crude oil, its derivatives and residues”.

These texts formalise the stipulations that apply to the rules for installing, operating, protecting and monitoring flammable liquid tanks.

These rules apply to all hydrocarbon tanks present at refineries. Nevertheless, the Prefect retains the right to change regulation stipulations for specific equipment.

These texts offer few regulatory parameters for taking into account ageing during the design, manufacturing, setting into service or modification phases.

There is however a regulatory requirement to perform a ten yearly internal sealing check on the recipients. This check may be replaced by an external sealing check.

This stipulation is presented in Article 504.5 of the Act of 9 November 1972:

“Tanks containing liquid hydrocarbons, except for heavy fuel oils, bitumen and grease, must undergo a ten yearly internal inspection so as to test for leakage. This stipulation is not applicable when technical measures are taken to detect any leaks from the tank base.”

Heavy oils (heavy fuel oil and bitumen) are not subject to this mandatory sealing check.

4.1.2 Design and Construction Codes

The regulations do not impose standards regarding tank construction characteristics. There are a number of codes, of which the main ones are stated below.

Commonly used construction codes and standards comprise:

- CODRES: "CODe de construction des REServoirs de stockage cylindriques verticaux" Construction code for vertical cylindrical storage tanks (France),
- BS 2654: "Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry" (United Kingdom),
- API 620/650: "Design and Construction of Large, Welded, Low-Pressure Storage Tanks" (United States),
- EN 14015: "Design and Construction of Large, Welded, Low-Pressure Storage Tanks" (Europe).

Tank design includes various parameters that influence ageing, which depend on the ordering party:

- Construction category: Based on the product and volume, it may be overestimated to increase safety,
- Design load choices: Predictable service load, typical loading (wind) and exceptional loading (earthquakes, fire) etc.,
- Safety margins in calculations: Safety factors, choice of materials, additional corrosion thickness, etc.,
- Construction parameters: Quality of assembly, welding, materials, coatings, admissible tolerances…

The version of the code used is also important as the codes evolve with feedback and as techniques evolve.

4.1.3 Guidelines

The inspection guidelines detailed in Annex A of this report correspond to the guidelines used in French refineries. There are three major references, the API standard (United States), the EEMUA guide (United Kingdom) and the UFIP guideline (France).

Guidelines	Reference
RBI method standards	API 580 API 581
FFS method standards	API 579
Inspection guidelines	**UFIP guideline - 2000** **EEMUA 159** API 653
Control selection guideline	UFIP/UIC guideline DT 75
Specific guideline	EEMUA 183

Remark: The RBI method guidelines API 580, API 581 and API 579, the principles and applications of which may also be used for atmospheric tanks, are not studied in this section. Please refer to the study undertaken in paragraph 3.2, in Annex A and to the General Benchmark.

4.2 RELEVANT DATA FROM THE LITERATURE

4.2.1 Degradation Mechanisms, Weak Points

The guidelines define a set of degradation mechanisms linked to structure ageing. The most frequently encountered degradation mechanisms are found in the list below.

- Overall and/or localised tank deformation due to non-uniform ground subsidence over the years. This may cause:
    - A tank **shell-bottom weld failure** due to a (local) stress concentration,
    - Tank ovalising (overall) and therefore **additional stresses throughout the entire tank** and the piping connected to it. This may lead to failures around the tappings,
    - **Local deformation and additional (local) stress** on the tank bottom. This may cause water retention pockets.

- **Shell buckling** caused by the wind. By design, this type of degradation is taken into account, whatever the code used. Nevertheless, shell or stiffener **corrosion** or **ground subsidence** may cause enough shell sinkage to trigger buckling. This may lead to deformation and possibly **failure of the upper shell walls**. This is a phenomenon also found to affect empty tanks following tornadoes (in the United States).
- **Tank roof cracking** due to **fatigue** affecting the centre web. These cracks may cause the floating tank roof sections to become filled with rainwater and therefore cause **the roof to sink**. These cracks may also **allow hydrocarbon vapours to escape**.
- **Reduced thickness** in tank component elements **due to corrosion**. This is the most widespread phenomenon. There are three cases of corrosion whose possible consequences are set out below:
  - **External corrosion** due to full time contact between the tank and the water in the atmosphere, trapped on the roof or under the tank. A number of factors may speed up or slow down external corrosion (e.g. a heated tank, bacteria in the ground, a hot and humid atmosphere, etc.).
  - **Corrosion under insulation** generally due to the poor condition of the insulation that lets water seep in. The water then becomes trapped in contact with the sidewall (it is retained or there is continuous runoff). This contact takes place in a hot atmosphere, accelerating corrosion.
  - **Internal corrosion** due to the products stored in the tank, the water in the products, insufficient setline and removal or due to tank breathing (condensing vapour damp). Exceptionally atomic hydrogen may also be found to have penetrated the steel (especially in the presence of H_2S) causing cracks (especially in the case of poor quality welding). These phenomena are the hardest to observe.

The consequences of any reduction in thickness are a mechanical weakening of the sidewalls and the possibility of cracking with the:

- Risk of a tank leak (due to a local loss in thickness) from the bottom and therefore ground pollution (hard to detect),
- Risk of tank cracking followed by tank rupture, at the shell or base level causing the tank to empty suddenly and potentially causing a wave effect,
- Risk of a tank shell-bottom weld failure causing the tank to instantly rupture and suddenly empty,
- Loss of the shell's mechanical strength, causing a greater buckling hazard (see above),
- Loss of tank roof sealing, leading to rain water seeping in, products (vapour) leaking out and in the worst case, roof subsidence (for floating roofs).

The **combined degradation** concept is present in all of the guidelines. This is because the risk of a tank integrity loss increases when a number of degradation phenomena are combined. For example, sidewall degradation due to corrosion may be combined with an unusual level of stress due to severe subsidence. This combination will strongly promote sudden tank rupture.

Over and above the general degradation mechanisms, there are a large number of specific points affecting atmospheric tanks and especially those with floating roofs. These are found especially in the above mentioned guidelines.

4.2.1.1 Non-Destructive Testing

There are various ways to perform tank inspection tests:

- **Visual examination** (*checking the overall appearance)*: see 3.2.2.
- **Magnetic-particle inspection** (*surface quality testing):* see 3.2.2.
- **Ultrasonic method (US)** (an internal examination and thickness measurement): see 3.2.2.
- **Alternative Current Field Measurement (ACFM)** (*weld and surface testing*): see 3.2.2.
- **Acoustic emissions method** (*an internal examination and corrosion measurement*): The structure is “listened” to when placed under load (i.e.: during filling). Evolving defects (evolving cracks, local plastic deformations) generate acoustic emissions that are used to locate and assess these defects. The advantage of this method is that it can be performed under load (with the tank filled).
- **MFL-Magnetic Flux Leakage method** (*an internal examination and thickness measurement*): By studying the propagation of a magnetic field created through the thickness of the sheet metal, the MFL method is used to detect variations in thickness and therefore corrosion areas. Data interpretation will sometimes give the residual thickness of a thin sheet of steel (< 15-20 mm). This method is often used for analysing tank bottoms.
- **SLOFEC-Saturation Low Frequency Eddy Current method** *(an internal examination and thickness testing*): This is a development of the MFL method described above. Here the principle is the same, only the sensor used to analyse the magnetic field is different. These sensors use eddy currents, thereby improving the quality and the depth of the study (> 30 mm) of the magnetic field. As a result, the SLOFEC method will provide a detailed (thickness) map of a steel sheet, for both sides. This relatively recent method is now often used for analysing tank bottoms.
- **Piezometer:** This method involves checking for the presence of products in groundwater using piezometers. This method does not allow any differentiation to be made between “old” and new pollution.
- **Internal level sampling:** This method involves precisely evaluating the product level in the tank so as to study any variation. A significant variation means there is a leak. This method does not detect small leaks.

4.2.1.2 General Methods Defined by Regulations

Tank regulations require a tank bottom sealing check every ten years for tanks that store light oils.

An internal visit is recommended to perform this check, but regulations do allow the use of alternative leak detection methods.

4.2.1.3 General Methods defined by UFIP Guideline 2000

The UFIP guideline targets liquid hydrocarbon tanks. It is written from a highly practical point of view. Nevertheless, it is a collection of recommendations that leaves the inspection departments free to adapt these methods to suit their own facility.

In inspection terms, the **UFIP guideline recommends**:

- **Regular inspections** by operators when operations are performed on the tanks. Any anomaly must be reported. The guideline recommends that these visits be defined in operating conditions.
- **Periodic inspections** aimed at monitoring paint condition, tank settling and the effects of external and internal corrosion (visible areas). Further, **the inspection department may perform thickness checks on the roof or shell** using the ultrasonics method. The frequency of these inspections must be suited to operating conditions, the corrosion rate and the sidewall thickness. **Indicative frequencies are given in the guideline** and are summarised in the following table.
- **Acoustic emissions (AE) test** on the tank bottom panels used to determine both the general corrosion status and to locate and weight the probability that a leak is present. **The interval between AE checks depends on the results of the previous checks**, **the corrosion rate, the thickness of the tank bottom panels and general operating conditions**. An indicative set of intervals before the next examination is provided in the guideline. **Critical results imply the need to schedule an inside visit** sooner.
- **An internal inspection** at a frequency that is dependent on all of the results of the previous steps, whether or not an inside coating is present, on the data provided by the leak surveillance systems, previous feedback from internal visits as well as the criticality of the leaks.

The guideline check-list comprises some sixty check points arranged by tank element, to be performed during the internal and/or external inspection.

The guideline refers to API standard 653 and EEMUA 159 for operations relating to the details of inspection methods and damage assessment. Nevertheless, it states that destructive tests may be performed when the tanks are opened, especially to test the external corrosion affecting tank bottom panels. A statistical study must be performed on sample cores taken from a number of points in the tank.

<table>
<tr><th>Storage service condition</th><th>Regular monitoring</th><th colspan="3">External inspection</th><th>Internal inspection</th></tr>
<tr><td></td><td>Operator rounds</td><td>Coating, seating and cleanliness</td><td>Inspection with corrosion check (thickness)</td><td>Acoustic emissions test</td><td>Inspection when empty</td></tr>
<tr><td>Ambient temperature</td><td>Regular (according to internal procedure)</td><td>1 to 3 years (according to local conditions)</td><td>3 to 5 years (according to past damage history)</td><td>0 to 10 years (depending on previous active corrosion stage and cracking)</td><td rowspan="2">Maximum of 20 years when coils are present for regulation requirement

No maximum for others (depends on product stored, inspection history and AE results)</td></tr>
<tr><td>Heated storage</td><td>Regular (according to internal procedure)</td><td>1 to 3 years (according to local conditions)</td><td>2 to 3 years (according to past damage history)</td><td>0 to 10 years (depending on previous active corrosion stage and cracking)</td></tr>
</table>

4.2.1.4 Methods Defined by US/UK Guidelines

The UFIP is based on the two reference guidelines in the US/UK, the API standard and the EEMUA guide. The methods found in these guidelines are detailed below.

API standard 653:
The API standard is developed on the basis of the API 650 construction code but it is specified that it may reasonably be used for all construction codes.

The **concepts of the Risk-Based Inspection and Fitness For Service methods are explicit** in the API standard (unlike in the UFIP guideline in which the method is not clearly mentioned) making reference to API standards 579, 580 and 581. As a result, the API favours these methods in terms of the choice of type and frequency of checks and of the occurrence of the hydrostatic test.

In inspection terms, the following steps are found:

- **A routine inspection** performed **at least once a month** by operators who know the tank and its contents. This comprises a visual check of the outside surfaces. Any anomaly must be reported to an inspector.
- **An external inspection** performed by a skilled inspector. This comprises a complete visual examination of the tank in service. It must be performed **at least every 5 years** if the corrosion rate is not known. **If the corrosion rate is known, then this value is modified** as shown in the table below.
- **An optional thickness test** using the ultrasonic method. The relevance of performing such a test is left up to the operator. If this test is performed, it must be performed **at least every 5 years** if the corrosion rate is not known. **If the corrosion rate is known, then this value is modified** as shown in the table below and the interval must **never exceed 15 years**.
- **An internal inspection** is recommended. This inspection should determine the degree of tank bottom corrosion, its minimum thickness and its integrity (no leaks). **The inspection frequency depends on the corrosion rate and the tank bottom thickness** determined during the last internal visit. Where the **corrosion rate is unknown, the interval between two visits must never exceed 10 years**. **The maximum interval must never exceed 20 years** except in cases where an RBI method is implemented. This method, presented in the guideline and expanded on in API 581, allows this duration to be extended by taking into account all of the information and known damage factors.

Two check-lists are to be found in the guideline, one for external inspection (one hundred points) and one for internal inspection (more than two hundred points).

Storage service condition	**Regular monitoring**	**External inspection**		**Internal inspection**
	Operator rounds	Inspection by authorised inspection department	External inspection by ultrasonics	Inspection while empty
N known	Max. 1 month	Min. between 5 years & RCA/(4*N)	Min. between RCA/(2*N) & 15 years	Min. between RCA/N & 20 years (*)
N unknown	Max. 1 month	5 years	5 years	10 years (*)

Where:

- ***RCA:** Residual thickness **=** thickness at last measurement – min. thickness called for by the code*
- ***N:** Corrosion rate per year*

(*): These frequencies must be considered in cases where no RBI method has been implemented. In such as case, the limits are set by the method.

<u>EEMUA 159:</u>

The EEMUA guide is written from construction code BS 2654 but it is specified that it may reasonably be used for all construction codes.

Initially the EEMUA approach comprises three inspection steps:

- **<u>A routine inspection</u>** performed by operators who know the tank and its contents. This check is performed **regularly with no more than 3 months** between two rounds. It must comprise a visual check of the outside surfaces. Any anomaly must be reported to the relevant department.
- **<u>An external inspection</u>** performed by a skilled inspector. This comprises a complete visual examination of the tank in service. The guide states that the time interval between each inspection is less important than the quality of the visual inspection performed. Nevertheless, it recommends the frequencies presented in the table below. An optional thickness check using the ultrasonic method can be performed during this external inspection. The guide provides indications for performing ultrasonic tests. It also proposes the use of simpler, less precise methods, but that allow a thickness test to be performed on a large surface (e.g. the electro-magnetic method).
- **<u>An internal inspection</u>** is recommended. This inspection should determine the degree of tank bottom corrosion, the tank's minimum thickness and its integrity (no leaks). **The inspection frequency depends on regulation conditions, the operator's experience of this kind of tank, operational conditions (product, temperature, climate, etc.) and the results of the checks performed during the last internal visit**. Frequencies are given as an indication, depending on the products stored. These are shown in the table below for a continental climate.

Two check-lists are to be found in the guide, one for an external inspection (one hundred points) and one for an internal inspection (more than two hundred points).

The concepts of Risk-Based Inspection (RBI) and Reliability-Centered Maintenance (RCM) are set out in the EEMUA that proposes to combine these two methods to achieve a probabilistic preventive maintenance application. The principle behind the so-called Probabilistic Preventive Maintenance-PPM method is to **combine inspection plans**, including a probabilistic approach to risk reduction, **with maintenance plans** involving a probabilistic approach to cost reduction.

The PPM approach results in the production of an inspection plan, a maintenance plan and a test plan (where possible) for each tank (or part of a tank) and for every accessory.

The necessary elements (logic diagram and calculation values) needed to perform the calculations are provided in Volume 2 of EEMUA 159.

Storage unit service conditions	**Routine inspection**	**External inspection**	**Internal inspection**
	Operator rounds	Full external inspection	Empty inspection
Heated or insulated storages	3 months*	3 years*	6 years*
Crude oil	3 months*	5 years*	8 years*
Lightweight petroleum products, treated water	3 months*	5 years*	10 years*
Heavyweight petroleum products not heated or not insulated	3 months*	8 years*	16 years*

(*) All of the frequencies are given for a temperate climate. The guide also provides values for tropical or desert climates.

4.2.1.5 Comparative Analysis of Methods

The inspection methods proposed in the API and EEMUA guidelines differ slightly from those presented in the UFIP guideline. There are however still many common points.

It should be noted that the UFIP guideline distinguishes between two types of external inspections as well as an acoustic emissions test.

In the API standard, only the external inspection and the ultrasonic corrosion measurement are presented. Nevertheless, the possibility of delaying the internal visit offered by using acoustic emissions may be compared with the use of the RBI method as called for in the API standard.

The EEMUA guide places the accent on the external visual inspection method. The ultrasonic method (US) is also recommended for checking the shell thickness. The AE (acoustic emissions) method is also presented but considered as an additional option.

The corrosion rate is used to modulate the inspection frequencies set in both guidelines and this is explicitly stated in the API standard unlike in the UFIP guideline. As a result, factors that may be considered safety factors are put forward in the API standard for the intervals between an external visit and between ultrasonic inspections. The safety factor is increased when the corrosion rate is not known.

The interval between internal inspections is recommended so as to reach the minimum thickness during the internal visit, except if this interval exceeds 20 years. The EEMUA guide treats products quite separately by setting generic interval values for each. In fine, the RBI/RCM method proposed is recommended for calculating these intervals.

The UFIP guideline especially develops the possible failure modes and protections in corrosion terms whereas for the API standard this concept is set out in special recommended practices (API RP 651 and RP 652).

The API standard develops the repairs to be performed in greater depth and the resulting hydrostatic test conditions.

The US/UK guidelines especially detail the monitoring and assessment of ground subsidence. They clearly tend towards RBI methods suitable for atmospheric storage tanks.

The RBI/RCM method in the EEMUA guide appears to be the only methodology encountered that simultaneously integrates risk, inspection and maintenance into atmospheric tank monitoring.

The API and EEMUA guidelines remain essential references for applying the methods described in the UFIP guideline 2000.

In the end, **both of these guidelines gear the inspection process towards the RBI method**. This method is however adapted to suit atmospheric tanks.

Overall, the EEMUA guide is the most complete of the guidelines studied.

4.2.2 Special Case of Coils

Heated tanks comprise heating coils that are not subject to regulatory sealing checks as heated products are heavyweight products.

Nevertheless, coils are subject to pressure regulations and consequently to the need for periodic requalification. This requalification is performed when the tank is emptied.

Special measures relating to inspection intervals are set out in BSEI No. 07-206 recommending the use of Professional Technical Specifications (Cahier Technique Professionnel or CTP) entitled "**Dispositions spécifiques applicables aux réchauffeurs de cuve the stockage**" or Specific measures applicable to storage tank heaters:

As a result, the periodic requalification may be performed at intervals of up to 20 years, which is possible subject to meeting the conditions set out in the CTP:

"*1-. The product contained in the tank does not, when in contact with water, give rise to a chemical reaction that may, immediately or in time, compromise the mechanical resistance or the integrity of the tank.*

The following substances are deemed to meet this condition when all of the tank's resistant parts are made of non-austenitic steel:

- ***Hydrocarbons from refining operations***
- ***Sulphonated hydrocarbons***
- ***Fluorinated or chlorinated hydrocarbons.***

2- The tank is properly protected against any risk of overpressure as a result of a clear break in a heater element.

3- The last heater test was performed at a pressure level that meets one of the following conditions:

- ***For heaters made under the terms of the amended Decree dated 2 April 1926, this is equal to:***
  - *Three times the boiler pressure if the latter does not exceed 6 bars,*
  - *The boiler pressure increased by 12 bars if the latter is greater than 6 bars but less than 12 bars,*
  - *Twice the boiler pressure if the latter exceeds 12 bars.*
- ***For heaters made under the terms of Title 2 of the aforementioned Decree dated 13 December 1999, the pressure is greater than or equal to the highest of the following two values:***
  - *2 x PS,*
  - *4/3 x PS x 1.25 (f ambient / f Ts)*"

CTP recommends checking safety devices linked to these tanks every 18 months.

The periodic requalification process comprises a visual external check and a hydraulic test. The devices are also tested on this occasion.

These tanks are therefore opened at least every 20 years. This opening is the opportunity to perform an internal inspection of the tank.

4.3 REFINERY PRACTICES

4.3.1 General Policy

Annex B constitutes a summary of all of the visits made to the six French refineries representing all of the industrial groups present on French soil. This section details elements presented in Annex B and the considerations developed above to draw conclusions from these visits.

Generally speaking, all of the operators visited use a method that is close to the UFIP 2000 method.

Some **operators are currently implementing an RBI or similar method** for inspecting atmospheric tanks. To date, these methods are in the design and test phase, or at best in the progressive application phase. To date, **none of the installations visited apply the RBI method** to all of their atmospheric tanks.

In Annex B, the current monitoring methods found at the sites visited are mentioned. The general monitoring policy consists of organising tank opening based on the following factors:

- Leaking tanks are opened as soon as a leak is detected,
- Tanks where the sealing test results are critical are opened up as a priority,
- The number of tanks opened up simultaneously is limited by operational requirements. Opening a tank means a 4 to 12 month shutdown period depending on the company,
- Opening a tank impacts all of the departments at a refinery (operations, cleaning, inspection, maintenance, etc.). It must be very carefully organised so that all of the actions are undertaken coherently, safely and as quickly as possible.

This policy aims to perform as many actions as necessary to keep tanks in service with a minimum number of tank openings. Once the tank is opened, numerous checking and maintenance actions are undertaken. The aim is to refurbish the tank for the longest possible in-service duration.

As a result, this type of equipment is not considered to have an overall service life, but rather a remaining service life, i.e. the time remaining before the next major maintenance action. This generally involves the tank being opened.

4.3.2 “Best Practices” and Key Considerations

This field study highlighted some quality practices that stood out during the visits. An analysis of these practices, a summary of the elements gained from discussions with experts in the field as well as concepts taken from the guidelines used by the entire profession have, without going into the technical aspects, allowed conclusions to be drawn on practices to be implemented to ensure that the integrity of atmospheric tanks is maintained.

First of all, it appears necessary to divide inspection into a number of complementary steps to ensure near full-time monitoring of tanks throughout their use:

- Frequent rounds should allow major anomalies that are visible from the outside to be detected, the progressive degradation of known anomalies to be monitored and any leaks at the shell level and at the tank base to be detected,
- An external in-service inspection should allow all of the external sensitive points to be controlled using visual checks that may be completed with NDT techniques. This inspection should also allow the evolution of corrosion to be monitored by measuring the loss of thickness in shell panels by applying suitable NDT techniques,
- An extensive internal inspection upon tank opening should allow a full survey of tank condition to be conducted using all of the suitable NDT methods.

Inspection frequencies should be adapted to suit storage-related hazards, knowledge of the storage and the results of prior inspections.

Furthermore, depending on the context, other complementary inspections and checks may be performed:

- Sealing checks performed in operation should ensure additional safety as regards tank bottom sealing,
- Geometric checks may be performed during the various inspections (external, tank opening) so as to validate the tank’s geometric stability. At sensitive locations (on unstable ground) these checks must be performed regularly. These measurements may be completed when the tank is opened for a base check performed by a surveyor. This check is used to detect abnormal deformations such as grooves.
- There do not appear to be any precise criteria for ground stability that may be used to trigger such checks.

The quality of each of the interventions depends on:

- The expertise of the various operators: The refineries employ **external contractors, companies that are generally audited and then certified for a set number of years** (2, 3, 5 years…). Inspectors use these audits and the inspector certifications so as to validate their work on-site. The results of the checks performed are used by RID inspectors whose expertise is validated internally and via external certification procedures such as UIC certification.

- The choice of methods: **The frequency, tools and location of the checks or maintenance actions are chosen on the basis of the experience** gained by the inspector and the checker, including feedback, prior knowledge of the equipment and the concepts set out in the guidelines.
- The reliability of methods: **Rarely subject to formal evaluation, this reliability** should allow confidence-weighting of the results and should consequently steer any subsequent decisions.
- The acceptability criteria: Generally defined in the construction codes, these criteria should be clearly recorded for every construction. For old constructions especially, a safety-related choice must be made as to the reference code to be applied. In some cases, Fitness For Service methods can be used to extend the deadline before opening and performing maintenance. Nevertheless, these methods must be covered by very strict procedures when it comes to recording data and performing calculations.

All of these methods should be implemented to avoid critical incidents. **In particular, the following typical degradation situations should be carefully monitored:**

- Corrosion affecting the tank bottom, the shell base or the junction between the two: Generalised or localised weakening may lead to a major leak or, in the worst case, the tank zipping open. The consequences of any such accident can be disastrous for people and for the environment.
- Floating roofs: These are subject to many ageing issues, with the main risk being of the roof sinking into the tank, causing the release of the gaseous cloud into the open air. Any such situation causes a major hazard as the tank's gaseous cloud may ignite.
- Foundation subsidence: This is a phenomenon that is poorly managed as few operators have regular checks performed on geometric tank aspects. Yet the consequences of any foundation subsidence can be disastrous in both the long and the short term. A modification to the resting points may cause deformations at any point in the tank, increasing the stress placed on it. Excessive overall or local deformation may cause component failure in the longer term.
- Local deformation affecting the tank bottom: Directly linked to modifications to support points, these deformations may be hard to detect. This is because unless a complete tank base map is made by a surveyor, these mainly elastic deformations may remain invisible when not under load (when empty). Yet these deformations may cause running water to be retained at the base of a tank in service. This situation, which was responsible for the incident at the Kallo refinery, may cause accelerated corrosion, making the corrosion rates deduced from former checks completely superfluous.

5. OUTCOMES OF EXCHANGES WITH PETROCHEMICAL OPERATORS

The facility visits as well as providing the opportunity to take part in the various working groups, made it possible to put forward various general observations on the inspections. This part covers five fundamental aspects. On the one hand, general themes such as service life concepts, monitoring operator expertise and equipment method reliability will be addressed, while on the other specific points will be covered, where major divergences occur regarding atmospheric storage of flammable liquids, AE checks and tank bottom anticorrosion treatments.

5.1 GENERAL REMARKS

5.1.1 Operator Expertise

Expertise is one of the keys to properly performing inspections. This aspect is deemed fundamental by all operators.

Operators agree that a large number of people are needed to perform all of the operations, especially when opening a tank. This is a long and costly operation to perform. The qualification and organisation of operations play a fundamental role at a number of levels.

To perform all of the actions linked to the inspection work, the operators call on outside contractors. The choices and checks relating to the expertise of these contractors are therefore fundamental.

Some practices that operators refer to as quality practices highlighted during visits:

- Long duration contracts so as to get to know the contractors,
- Checking and certifying the contractors,
- Regularly auditing the contractors,
- Having one-off checks performed on the work by “third party checkers”,
- Preferring to process data internally,
- Working in internal/external pairs,
- Performing collaborative maintenance/inspection work,
- Having sensitive actions performed by internal inspectors.

5.1.2 Service Life

Equipment design ensures the minimum geometry required to guarantee resistance to the maximum loads that will be imposed. Nevertheless, a certain number of safety margins must be noted. The minimum calculation thickness is the sum of:

- A resistance thickness, resulting from a maximum operating load and a type of material. The material's theoretical resistance values and service load are weighted by safety factors,
- A manufacturing tolerance,
- An excess corrosion thickness.

In practice, construction choices are made from a catalogue of sheet steel of standardised thicknesses. The real thickness of the sheets will exceed the calculation value, thereby adding an extra safety factor.

As a result, by knowing the geometric design parameters (minimum resistance thickness and true thickness) and the degradation parameters (corrosion rate), it is theoretically possible to estimate a device "service life".

In practice, a number of observations make any such calculation purely formal:

- The theoretical values for degradation rates may be far different from reality, as many factors influence these theoretical rates (product, temperature, environment, etc.),
- Localised degradations generally follow faster evolution rates than known evolution rules,
- A number of degradation mechanisms are not time-related but rather related to operating conditions,
- The maintenance of faulty elements (e.g. tank bottom panels) makes it possible to considerably modify estimated service life values.

It is not therefore reasonable to estimate an overall service life when equipment enters service.

Nevertheless, remaining service life or service life duration concepts are possible under certain conditions that can be found, in particular, in the FFS guidelines:

- Degradation mechanisms must be known and their causes and effects manageable. When it comes to the corrosion rate, all of the rates (long term, short term and theoretical) need to be analysed and taken into account,
- Operating conditions must be manageable, documented/traced and monitored,
- Inspections must be undertaken regularly to check equipment behaviour,
- More frequent inspections must be performed when an exceptional operating condition appears that may lead to fast-acting degradation mechanisms,

- Inspections must be undertaken when major changes are made to the operating conditions or are found in the inspection results,
- Investigations must make it possible to justify any unusual variation in structure behaviour.

The remaining service life concept is therefore directly dependent on the inspection and maintenance results.
The remaining service life must at least represent the local remaining service lives of the various components together with the degradation kinetics. This must be reassessed after every modification made to the equipment (check, maintenance, etc.) as well as for every modification made to the equipment environment or to its operating process (product, temperature, etc.).
The remaining service life determined in this way, subject to including suitable safety margins for the given risk, allows inspection methods and maximum frequencies to be defined as well as the required maintenance operations. Together, this data is used to formalise the inspection plan. The inspection plan defined in this way necessarily makes reference to an acceptable degree of risk. In fine, the equipment end of life represents an unmanaged risk situation together with repairs that are impossible or not economically viable.
With a view to developing ageing-related risk management, it would be interesting to compare the risk levels assigned to each item of equipment in the inspection plan with those defined in the safety report.

5.1.3 Inspection Method Reliability

All of the inspection practices are based on the results of visual inspections or non-destructive testing. Whatever the equipment, these methods have a direct influence on the choice of inspection services and on the quality of any monitoring. A number of incidents have shown that despite suitable checks, an inspection may overlook by non-negligible flaws.

While the selection of appropriate inspection methods for the equipment and its degradation mechanisms seems to be well defined in the guidelines, **the reliability of their results remains specific to each facility or even to each inspector.** As a result, a number of methods can be found that may yield varying appreciations for each kind of check.

The data processed in this study highlights the key points in an evaluation of NDT methods. The aim is to evaluate the quality of the results of any check and to manage the error margins inherent to the test.

This reliability must be evaluated according to the level of confidence granted to the operator (certifications, experience, etc.), the sensitivities of the method (feedback, input parameters, adjustment, etc.) and the implementation conditions (weather conditions, condition of tested surfaces, number of points, etc.).

The reliability defined in this way may guideline the choice of inspection frequencies, the number of additional checks to be implemented, the number of points inspected, etc.

5.2 SPECIFICITIES OF ATMOSPHERIC STORAGE TANKS

5.2.1 Leak Detection Using Acoustic Emissions

In France, many operators perform acoustic emission checks to delay tank opening as much as possible. This check involves using instruments to "listen" to the noise of active corrosion and/or leaks. This method draws upon two parameters:

- The overall noise level due to generalised corrosion so as to determine the general corrosion level. This is represented by a letter from A to E.
- The localised signal intensity caused by corrosion peaks or leaks, so as to highlight a peak tank corrosion/leak level. This is represented by a number from 1 to 5.

This is a controversial method among operators (both French and non-French) and does not seem to be suitable for validating equipment integrity on its own. Criticism of this method includes:

- The method is not recommended by internationally recognised guidelines like API 653 and EEMUA 159 as a fully fledged method for checking storage tank bottom integrity.
- The method's results seem to vary considerably depending on:
    - Implementation conditions (outside noise, wind). These may severely interfere with the inspection,
    - The interpretation of the results, which is dependent on the checker, with the need to translate acoustic measurements into letters and numbers,
    - The interpretation of the letters and numbers, which is specific to each facility. UFIP 2000 provides a matrix which serves as a basis for operators. Nevertheless, operators have sometimes developed their own more severe matrix.
- The method measures active degradations (on-going corrosion and leaks) but does not give the corrosion status of the panels,
- The method does not allow any detection of bacteriological corrosion,
- At present, there are few studies for correlating inspection results with the true condition of the tank bottom.

This method should therefore be used with care, both in its implementation and in the processing of results. In particular, delaying any tank opening should not be determined solely on the basis of these results. It seems necessary to analyse all of the tank inspection results and to correlate these results with the remaining service life calculated on the basis of a known and practical corrosion rate.

In other words, acoustic emissions should be used in addition to conventional methods (see 4.1.3) and are intended primarily for detecting active leaks.

5.2.2 Preventive Maintenance: Anticorrosion Coating

Preventive maintenance is an integral part of any tank management policy and the **methods and choices applied in this field vary from one operator to another.**

During the visits and discussions, differing points of view on maintenance were expressed. This relates to the anticorrosion coating, generally made from epoxy, applied to the tank bases.

Most operators agree that a specific coating applied to the tank bottom provides real protection against corrosion. Nevertheless, some operators have expressed reservations regarding this kind of protection. A number of constructive remarks are presented here regarding the precautions to be taken:

- First of all, the coating must be considered as a protection system and not a repair system, as a result, the coated surface must be carefully repaired and prepared before applying any reinforcing coating.
- Achieving application quality is complex, especially as the thickness and adherence of the product applied must be checked. The application must be meticulously validated by an experienced inspector. This is because a poorly applied coating offers little protection and on the contrary may even become a trap for running water which will in turn lead to an acceleration in the corrosion phenomenon.
- The coating must not be considered to offer total equipment protection. This is because other forms of degradation, like external tank bottom corrosion or geometric deformations still have to be considered.
- Lastly, the ageing behaviour of the coatings themselves is poorly known. Some operators state that 15 or 20 years after application, the protection has not been significantly modified while others state that coatings have become seriously deteriorated after just a few years. As for the contractors that apply coatings, they provide a ten year guarantee.

Anticorrosion coatings currently represent the best way to protect tank bottoms from internal corrosion phenomena. Nevertheless, care needs to be taken regarding the choice of coatings used and the way they are applied. Lastly, it is necessary to gain useful information on how the selected coatings behave over time.

6. CONCLUSION

Recent accidents remind us that industrial installations require rigorous monitoring of storage tanks to be set up at refineries so as to manage ageing.

An analysis of storage monitoring principles (regulations, guidelines and real life situations) at French refineries has highlighted the existence of highly variable monitoring methods, depending on the type of equipment monitored (pressure equipment and storage tanks), on the industrial operator’s group policies and on applicable regulations.

Regardless of the monitoring policy, the skills of the inspection stakeholders are essential in ensuring quality storage facility monitoring. This especially relates to how external staff are managed and the fact that their expertise must be formally validated.

For every inspection phase, the use that is made of the Non-Destructive Testing results must take into account the degree of reliability attributed to the method. This depends on operator skills, instrument sensitivity and implementation conditions.

Pressure equipment is rigorously monitored, based on regulatory requirements and on the Risk-Based Inspection method.

In particular, LPG storage (propane, butane) is not subject to internal corrosion, so inspections can be concentrated on outside aggressions, which are the easiest to detect. Nevertheless, an analysis of field practices has shown that implementing RBI methods yields results that vary from one facility to another, despite a common general method being applied.

The following conclusions can also be drawn, regarding the monitoring of pressurised LPG storage at refineries:

- The accident review shows that accidents affecting LPG storage that are caused by installation ageing remains rare,
- RBI methods applied to LPG storage facilities yield inspection intervals that are far longer than regulatory inspection requirements. This limits the monitoring of this equipment to regulatory inspections,
- The absence of internal corrosion justifies the absence of any internal inspection visits for the tanks,
- The accent must be placed on aggressions to the outside of the tanks (water dripping, water retention, etc.). To do this, in-depth and frequent visual inspections seem to be effective.

- Analysis of the atmospheric pressure storage tank inspection methods has shown that industrial stakeholders are converging towards an overall method, as formally set out in the UFIP guideline 2000. Nevertheless, the extent and type of checks remain highly variable from one facility to another and a number of points show divergence. A number of operators are progressively heading towards RBI methods.

The following conclusions are drawn for monitoring atmospheric pressure storage tanks at refineries:

- The accident review shows that:
  - Current inspections are not sufficient to ensure the integrity of atmospheric pressure storage tanks,
  - Crude oil tanks suffer from more extensive corrosion than tanks storing other products at refineries,
  - The geometric instability affecting tank settling may be a cause of severe failure.
- An analysis of inspection methods (guidelines, regulations, practices) has shown that:
  - The principle of three inspection steps (routine checks, external visit and internal visit) is used in all of the reference procedures and should ensure reliable tank monitoring.
  - These inspections should allow appropriate inspection methods for the storage facilities and operating conditions to be implemented, according to the results of previous inspections.
  - Any modification must be taken into account in the inspection-related choices made. This especially means that maintenance and changes in operating conditions must be covered by full time monitoring.
- All of the information collected has made it possible to highlight a number of important remarks:
  - Foundation checks including checking seating and geometric aspects applying to tanks must not be neglected,
  - Acoustic emission checks must be considered more carefully than at present as regards their implementation and the way their results are used,
  - Anti-corrosion coatings require special attention when they are applied.

Whatever the kind of equipment, an overall service life is meaningless in industrial service. A remaining service life concept can however be calculated. It must take into account all of the degradation mechanisms that are time-dependent and it must be suited to the equipment's operating conditions, to equipment related acceptability criteria and to knowledge of the equipment (design, inspection and maintenance). This remaining service life must be evaluated regularly and must allow the inspection frequencies and applicable methods to be determined so as to always retain an acceptable risk situation as regards equipment ageing.

With a view to improving age-related risk management, the degree of risk accepted, whether implicitly or explicitly, by the inspection plan should be coherent with the risk levels as assessed in the safety report.

To reach a managed risk situation, the fundamental approach involves, as always, finding the best possible balance between the acceptable degree of risk through inspection plans and the costs generated by inspection practices.

7. LIST OF ANNEXES

Mark	Precise description	Number of pages
A	Presentation of the main guidelines relating to the inspection of storage facilities used at refineries	9
B	Summary of refinery visits	15

8. REFERENCES

REGULATION, STANDARD AND PROFESSIONAL GUIDELINE REFERENCES:

	PRESSURE EQUIPMENT
1.	European Pressure Equipment Directive: 97/23/CE dated 29 May 1997
2.	Initial amended decree dated 18 January 1943 regulating pressure equipment
3.	Decree No. 99.1046 dated 13 December 1999 relating to pressure equipment, later amended by Decrees 2003-1249 of 22 December 2003 and 2003-1264 of 23 December 2003
4.	Act of 21 December 1999 relating to the classification and compliance evaluation of pressure equipment
5.	Act of 15 March 2000 modified, relating to operating pressure equipment (modified by the Act of 13 October 2000 and the Act of 30 March 2005)
6.	Instruction DM-T/P No. 32510 dated 21 May 2003 relating to “Recognition of the Inspection Department at an industrial facility”
7.	Circular BSEI No. 06-080 dated 6 March 2006
8.	Circular BSEI No. 06-194
9.	Circular BSEI No. 07-107
10.	Circular BSEI No. 05-139
11.	Act of 22 June 2005 approving APAVE Group, ASAP and Bureau Veritas.
	Other guidelines used in pressure equipment regulations (general)
12.	AFIAP guideline: “Le guide de bonnes pratiques pour les contrôles par émission acoustique des équipements sous pression” (Guide to best practices for acoustic emission inspections for pressure equipment) - General and Annex 1 dated May 2004 + Annex 3 dated May 2004 (spheres) + Annex 4 dated June 2005 (so-called small bulk LPG tanks) + Annex 6 dated May 2004 (cylindrical pressure equipment) – Approved by BSEI No. 07-107 dated April 2007.

13. AQUAP guideline: “Inspection réglementaire des équipements sous pression revêtus extérieurement ou intérieurement” (Regulation inspection for pressure equipment with an outside or inside coating) - Revision 2 – December 2005 – Approved by BSEI No. 06-011 January 2006

14. AFIAP guideline: “Le guide de classification des modifications ou réparations de tuyauteries d’usine soumises à la réglementation française” (Guide for classifying modifications or repairs to factory piping subject to French regulations) - February 2004 – Approved by DM-T/P No. 32 969 dated May 2004

15. AQUAP guideline: “Le guide de classification des modifications ou réparations des équipements sous pression soumis à la réglementation” (Guide for classifying modifications or repairs to pressure equipment subject to regulations) - Revision 3 – March 2004 – Approved by DM-T/P No. 32 969 dated May 2004

General guidelines for producing inspection plans (France)

16. Guide for establishing inspection plans (IP and PR 5 and 10 year intervals) - UIC/UFIP/CTNIIC document DT 32 revision 2 – June 2008

17. Guide for establishing inspection plans for defining the type and frequency of periodic inspections and requalifications that may exceed five and ten years - UIC/UFIP document DT 84 - June 2006

Guidelines relating to Fitness For Service (FFS) or Fitness For Purpose (FFP)

18. API 579-1: “Recommended practice for Fitness-for-Service”, June 2007

19. British Standard BS 7910:2005 – Guide to methods for assessing the acceptability of flaws in metallic structures, British Standards Institution, London, 2005

Note: Former standard PD 6493:1991 – includes procedure PD6539:1994 for high temperature assessment

Guidelines - RBI methods

20. API 580: “Risk-Based Inspection” 2002

21. API 581: “Base Resource Document on Risk Based Inspection” 2008

22. API 510: “Pressure Vessel Inspection Code” 2006

23. API 570: “Piping Inspection Code” 2003

Other guidelines

24. EEMUA Publication 193, Recommendations for the training, development & competency assessment of inspection personnel, 1999 (to be confirmed if analysis)

25. API 571, damage mechanisms affecting fixed equipment in the refining industry, 1st edition, December 2003

26. DT 75 – Guide for choosing inspection methods for materials and equipment - May 2002

Construction code:

27. CODAP: Construction code for pressure equipment – SNCT

ATMOSPHERIC PRESSURE STORAGE TANKS

28. Ministerial acts dated 9 November 1972 and 19 November 1975: Setting up and operating liquid hydrocarbon storage sites.

29. Ministerial Act dated 4 September 1967: Setting up and operating treatment plants for crude oil, its derivatives and residues.

30. Circular BSEI 07-206

31. Guide for inspecting and maintaining above ground vertical cylindrical metal liquid hydrocarbon tanks at refineries – UFIP – Edition August 2000

32. EEMUA Publication 159, Users' guide to the inspection, maintenance and repair of aboveground vertical cylindrical steel tanks, ISBN 0 85931 1317, 3rd edition, 2003

33. EEMUA 183, Guide for the prevention of bottom leakage from vertical cylindrical, steel storage tanks

34. API 653: "Tank Inspection, Repair, Alteration and Reconstruction" 2008

35. AFIAP professional technical specifications: Specific measures applicable to storage tank heaters

36. Doctrine memo dated 15 October 2008 – BRTICP/2008-514/CBO: Wave effect at flammable liquid storage sites (including storage at industrial facilities such as refineries)

Annex A

Presentation of the main guidelines related to the inspection of refinery storage facilities

1. GENERAL METHODOLOGY GUIDELINES (RBI AND FFS)

Since the early 1990s, two methods have appeared in France based on US institutions.

The first, “Risk-Based Inspection (RBI)”, involves inspection plans being drawn up based on criticality, and the second, “Fitness For Service (FFS)”, is a method for assessing whether equipment is fit for continued service.

- **The “Risk-Based Inspection (RBI)” method** involves **planning the inspection according to the risk** entailed by a structure’s failure.
  As such, the risk is measured on the basis of the probability that the equipment will fail combined with the expected consequences of this failure. The degree of risk as determined in this way will allow equipment to be classified and inspection actions to be determined, with the aim of minimising any risk and targeting inspections towards the equipment that is most at risk.

  This is especially the basis used to produce the UFIP/UIC DT 32 and DT 84 guidelines used by the RID in implementing inspection plans.

  The guideline that presents the general method is published by the American Petroleum Institute as API 580 “Risk-Based Inspection”. This guideline provides the basic steps to be followed to establish an inspection plan. Nevertheless, it does not provide any practical methods, which are found in API 581. The latter guideline is frequently updated and the latest version dates back to September 2008. A brief summary of it is presented in the General Benchmark (Annex G).

- The principle behind the **“Fitness For Service (FFS)” method** is to assess the structural integrity of equipment for subsequent service (often until the next shutdown or inspection), taking into account degradation and deviations in relation to design conditions. **API 579 “Recommended practice for Fitness-for-Service” is the reference guideline** used for this purpose by US bodies.

  This guideline is used when any doubt arises on **maintaining the equipment in service until a given deadline**. This is, for example, the case when, based on the corrosion rate, a calculation is made as to when the minimum thickness required will be reached (without any additional corrosion thickness). A margin of tolerance will then be applied to allow for the margins used in the equipment design. **The accepted tolerance then, in theory, depends on the margins taken into account during design and on the construction codes used**.

  The fundamental principles of this method can be found in the FFS part in the General Benchmark in Chapter 9. The method is applied by qualified staff.

2. PRESSURE EQUIPMENT (PE) GUIDELINES

2.1 GUIDELINES FOR PRODUCING INSPECTION PLANS

Producing an inspection plan constitutes the fundamental part of the work performed by RIDs. In France, two UFIP/UIC guidelines are approved by the Ministry for producing these plans. They are presented here:

2.1.1 UFIP/UIC Guideline DT 32: "Guide pour l'établissement des plans d'inspection – Périodicité d'Inspection Périodique 5 ans et de Requalification Périodique 10 ans" (Guide for establishing inspection plans - Inspection periodicity of 5 years and requalification periodicity of 10 years)

This guideline is intended for RIDs for creating the pressure equipment inspection plan.

It is used to modulate periodic inspection and requalification frequencies (for AM 15/03/00) by evaluating the criticality of the equipment, implementing suitable checks during the inspections, implementing specific monitoring checks and taking into account feedback and boundary service conditions.

This guideline provides:

- Elements for evaluating criticality (analogous to the CODAP and CODETI construction category),
- Elements that influence the frequency, the full implementation of checks and the results,
- Elements required in the inspection plan for:
    - PE depending on their type (possible changes for specific PE),
    - Insulated equipment (conditions for removing insulation during inspection and for requalification purposes),
    - Piping,
    - Accessories,
- Elements for choosing the tests according to degradation mechanisms (presented briefly),
- Documentation sources and suggestions for developing and improving plans,
- Measures applicable to some PE families (with coatings or comprising absorbing catalysers or internal linings).

2.1.2 UFIP/UIC Guideline DT 84: "Guide pour l'établissement des plans d'inspection – Périodicité d'Inspection Périodique 6 ans et de Requalification Périodique 12 ans" (Guide for establishing inspection plans - Inspection periodicity of six years and requalification periodicity of 12 years)

This guideline is intended for RIDs, where recognition dates back at least five years to support the creation of a PE inspection plan on the basis of an RBI method.

The principle is to detail the elements required to evaluate the criticality of the equipment by including all of the parameters needed to refine the evaluation. Furthermore, this guideline includes the concept of a strong degree of feedback along with concepts of damage kinetics and the sensitivity of materials.

We note that the use of each of the two guidelines is exclusive to a given item of equipment. More generally, the use of a guideline is exclusive to all of the equipment under the responsibility of the same RID.

In addition to the elements in DT 32, the guideline comprises:

- Elements for evaluating criticality that are more detailed than in DT 32 (probability of failure * consequences),
- Elements to be taken into account when implementing monitoring conditions,
- Detailed conditions for periodic inspections and requalification,
- Inspection particularities for tanks made in series production using a representative equipment unit,
- Documentation sources and conditions for integrating and managing feedback,
- Conditions for revising the inspection plan,
- Conditions for revising the guideline,
- Measures applicable to equipment comprising non-corrosive fluids,
- Measures applicable to equipment that cannot be requalified,
- Information on taking into account Critical Operating Condition Limits.

The US equivalent of these guidelines is presented hereafter.

2.1.3 API 510: "Pressure vessel inspection code: In-Service Inspection, Rating, Repair and Alteration"

This US standard is used to produce a pressure vessel inspection plan by an "Authorized Inspection Agency".

It is based on the RBI method presented in API 580 for which practices are detailed in API 581. The entire document refers to these texts.

We can consider that this standard is the US equivalent of DT84 for RID.

The content and method for producing the plan are similar. This is a collection of recommendations destined for a skilled inspection department responsible for producing an inspection plan for pressure vessels. It forms a basis that may be used without applying the entire RBI method. Nevertheless, the latter is strongly recommended.

This standard provides:

- Elements for producing, implementing and revising the inspection plan,
- Elements on the various monitoring steps (rounds, internal, external inspections, etc.),
- Elements on monitoring frequency in cases where the RBI method is not used,
- Elements on evaluating the results of any checks,
- Elements on pressure vessel repair methods,
- Conditions relating to specific equipment families.

2.2 ADDITIONAL GUIDELINES

In addition to the guidelines presented above, there are a number of guidelines issued by professional organisations that appear to provide assistance with decision making.

2.2.1 UFIP/UIC guideline DT 75: "Guide pour le choix des méthodes de contrôle des matériaux et équipements" (Guide for choosing material and equipment inspection methods)

This guideline is intended for mechanical equipment inspectors to assist in choosing which tests to perform. It is not apparently specific to pressurised tanks.

It is not self-sustaining as the information provided is general in nature. It is necessary to refer to the standards corresponding to each type of non-destructive test so as to gain further details.

The guideline takes the form of a classification of testing methods by type:

- Overall methods for performing a general study of the equipment,

- Local methods for detecting material surface or core defects,
- Identification methods used to characterise equipment materials,
- Other methods such as residual thickness measurements or geometric measurement methods.

For every test, general elements are provided on:

- Main methods,
- Mechanisms to be implemented,
- Performance expected,
- Limitations to the method.

The guideline also provides a list of standards relating to the various tests along with a table showing the correspondences between the type of flaw sought and the method used.

2.2.2 AQUAP Guideline: “Inspection réglementaire des équipements sous pression revêtus extérieurement ou intérieurement” (Regulatory inspection of pressure vessels with an outer or inner coating)

This guideline, intended for inspectors, provides details for establishing the examinations to be undertaken as part of the inspections on insulated PEs. These recommendations are provided according to the device’s hazard level.

First of all, it should be remembered that the following are excluded from the scope of this procedure:

- Piping,
- Pressurised equipment that is monitored by a Recognised Inspection Department within the scope of its expertise,
- Equipment covered by regulations, a DM-T/P decision, a BSEI decision or by professional technical specifications (CTP) approved by the Minister in charge of industry, who specifies the measures to be taken as regards the coatings, the insulation coatings or other linings for in-service inspection.

The basic principle to be retained is that for equipment in service, the insulation in place is assumed to be harmless to the sidewalls if no degradation to the sidewalls is observed in those areas that are partially stripped of insulation and examined.

Sealed insulation mechanisms (protection envelope welded to the outer walls or similar) are assumed to continue to be non-damaging and fully sealed in the absence of any suspicion raised during the visual examination.

Thin coats of paint and galvanisation are not considered as coatings that may interfere with inspection, as the proper condition of the sidewall can be evaluated from the condition of the coatings themselves. This is especially corroborated by the DGAP5/3 Q/A form in DMTP 32140.

Consequently, depending on which inspection is to be performed, the guideline proposes four levels of insulation removal, from the simplest to the most complete.

2.2.3 AQUAP Guideline: "Le guide de classification des modifications ou réparations des équipements sous pression soumis à la réglementation française" (Guide to classifying modifications or repairs to pressure vessels subject to French regulations)

This is a guideline that assists in classifying work performed on the pressure vessel.

This guideline (AQUAP 99/13) is used to classify the interventions performed on the pressure vessels into two categories. Checks or tests prior to returning to service are to be implemented depending on the category of the work performed.

If the repairs are deemed "non-notable work", this guideline lists the non-destructive testing and inspections needed to validate repair compliance.

If the modification is deemed to be "notable work", then some relevant checks and a hydraulic test must be performed before validating repair compliance and allowing a return to service.

2.2.4 AFIAP Guideline: "Le guide de bonnes pratiques pour le contrôle par émission acoustique des ESP" (Guide to best practices for checking PE by acoustic emission)

This guideline is intended for pressure vessels where a hydraulic test can be replaced by another test such as a pneumatic test using acoustic emissions.

3. ATMOSPHERIC STORAGE TANK GUIDELINES

3.1 UFIP- 2000 GUIDELINE

"**Guide pour l'inspection et la maintenance des tanks métalliques aériens cylindriques verticaux d'hydrocarbures liquides en raffinerie**" (Guide to inspecting and maintaining aboveground vertical cylindrical metal tanks containing liquid hydrocarbons at refineries)

This guideline is intended for the inspection department so as to implement the essential stipulations relating to the inspection and maintenance of aboveground storage tanks **containing liquid hydrocarbons**. This guideline is very different from the pressure vessel guidelines as it takes on a far more practical approach. The following elements are found:

- The **three main known failure modes** are detailed, and acceptability thresholds are defined,

- The main **means for managing corrosion** (the most frequent degradation mechanism) are set out for the following periods:
    - Design/manufacture (prevent water trapping, excess corrosion thicknesses, draining, etc.),
    - Operation and maintenance (draining, preventive seal maintenance, etc.),
    - Choosing materials,
    - Choosing forms of protection (paint and coatings, cathode protection, chemical additives),
    - Checking corrosion protection mechanisms.
- A brief description of **means used to inspect** and evaluate damage,
- A detailed listing of the points to be checked when inspecting a tank. This part is highly detailed and very practical. A distinction can be made between:
    - **Routine monitoring,**
    - **Brief external inspection and/or complete external inspection (with corrosion analysis),**
    - **External inspection using acoustic emissions and/or internal inspection**.
- Recommendations on inspection frequencies according to temperature conditions,
- A **hydrostatic test** is required if major modifications are made.

3.2 US API STANDARD 653

“**Tank Inspection, Repair, Alteration, and Reconstruction”**

This standard is intended for the inspection department so that they can implement essential stipulations relating to the inspection and maintenance of tanks **built based on API standard 650**. Different from pressure vessel guidelines, API 653 includes practical parameters in the approach. The following elements can be found in the standard:

- Known **failure modes** are detailed and **acceptability thresholds** defined,
- The main **means of damage inspection and evaluation are presented**,
- A brief description is provided of **means for inspection** and evaluating damage,
- A detailed listing of points to be checked when inspecting a tank. This part is highly detailed and very practical. A distinction is made between:
    - **Routine monitoring,**

        - **External inspection,**
        - **Corrosion analysis using ultrasonic thickness measurements,**
        - **Internal inspection**.
- Recommendations on **inspection frequencies** depending on the knowledge of annual tank corrosion rates,
- Recommendations relating to **repairs and rebuilding,**
- A **hydrostatic test** is required when major modifications are made,
- **Conditions** are set out for the use of an **RBI and/or FFS method,**
- The necessary elements are provided for **certifying inspectors** and **qualifying inspection operators.**

3.3 BRITISH GUIDE EEMUA 159

"**User's guide for the inspection, maintenance and repair of above ground vertical cylindrical steel storage tanks**"

This guide aims to provide the essential prescriptions relating to the inspection and maintenance of aboveground vertical cylindrical storage tanks. The guide is built on a practical basis and it may be used without further reference. The following elements are presented:

- The **main degradation mechanisms** and their consequences,
- The main **inspection methods** and **checklists** of points to be checked. Here a distinction is found between:
    - **Visual inspections during rounds,**
    - **Complete external inspection,**
    - **Internal inspection.**
- A preventive maintenance method that includes risk and cost. This method is mapped on an RBI method coupled with a preventive maintenance method based on failure probabilities (Reliability Centered Maintenance). It includes costs in a way that is analogous to risk.
- A detailed analysis of all **sensitive tank parts.** For each part, this includes:
    - The various **possible degradation mechanisms**, related causes and consequences,
    - **Detection methods** and inspection **acceptability criteria**,
    - Practical elements for operation and maintenance,
    - **Possibilities for repairs** depending on degradation.
- A **detailed hydrostatic test** as well as the conditions that lead to it being performed (major alterations),

- Recommendations on **inspection frequencies** depending on operating conditions (what products are stored, climate, refrigerated or heated storage, etc.).

3.4 ADDITIONAL GUIDELINES

In addition to the guidelines presented above, there are a number of other guidelines issued by professional bodies that are used to support decision-making.

3.4.1 UFIP/UIC Guideline DT 75: "Guide pour le choix des methodes de contrôle des matériaux et equipements" (Guide for choosing material and equipment inspection methods)

This guideline is intended for mechanical equipment inspectors to help them in choosing the inspections to be performed. Its content is presented in Chapter 2.2.

3.4.2 EEMUA 183: "Guide for the prevention of bottom leakage from vertical cylindrical, steel storage tanks"

This guide covers the main form of degradation affecting atmospheric storage tanks, namely tank bottom leakage. This is a collection of information and recommendations aimed at improving the integrity of storage tank bottoms.

This guide comprises:

- Recommendations on tank bottom design,
- Detailed elements on possible causes of leaks (degradation mechanisms),
- Elements on inspections and tests for detecting leaks while in or out of service,
- Elements on protection methods applied in relation to possible degradation as well as a classification of these methods (by efficiency and cost).

Annex B

Summary of refinery visits

1. CONTEXT

As part of its work on managing ageing in the prevention of technological hazards as requested by the French Ministry of Ecology, Energy, Sustainable Development and the Sea, INERIS visited six refineries in France between May and June 2009.

The purpose of these visits was to record practices observed in the field as applied to the inspection and maintenance of piping and storage tanks, to the management of feedback and the management of the skills and qualifications of staff involved. The safety measures and civil engineering works relating to the piping and storage tanks also fell within the scope of this study.

For each of the six refineries, a day of discussions took place between two INERIS engineers and facility representatives (inspection department, corrosion expert, maintenance expert, HSE, etc.) and in some cases with the head office of the oil company operating the refinery. The elements collected during these visits have in part been included in the various reports published[1]. A summary is also presented hereinafter.

INERIS wishes to thank all of the persons involved during these visits, and who by sharing their experience contributed to this evaluation.

2. SUMMARY OF VISITS

2.1 Inspection Department

All of the refineries visited had a Recognised Inspection Department (RID) in accordance with the demands of Circular DM-T/P No. 32510 dated 21 May 2003. The RID is tasked with ongoing monitoring and inspection of pressure equipment that comes under the terms of Title III in the Decree dated 13 December 1999 in compliance with the terms defined by in-house procedures, with a view to guaranteeing personal and property safety and to contributing to environmental protection.

In all cases, Inspection Department recognition was received a number of years ago. Currently, they apply the standards of UIC/UFIP guideline DT 84 to develop their inspection plans and have freedom to perform periodic inspections and requalifications every 6 and 12 years.

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[1] Industrial installation ageing management; general report; DRA-09-102957-07985C.
Industrial installation ageing management; refinery storage; DRA-102957-08289B.
Industrial installation ageing management; refinery piping; DVM-09-102957-08343A.

Before using UIC/UFIP guideline DT84, these RIDs often used various other guidelines to establish their inspection plans, such as UFIP 2000, UIC DT32 or even the guideline for steam crackers and interconnected units.

Staff numbers at these RID are between 10 and 18 persons overall, depending on the size of the refinery and whether or not their scope extends to a steam cracker and to related chemical activities.

Their assignments include analysing equipment criticality, drawing up inspection plans, scheduling and monitoring of these plans, supervising inspections, managing feedback, etc. Generally, non-destructive testing is assigned to specialist contractors and RID staff use the results obtained.

Each of the RIDs visited is tasked with monitoring many thousand PE (excluding piping).

2.2 RBI Approach

All of the refineries visited are committed to an inspection approach that is based on risk evaluation, and this has been applied since the early 1990s for the forerunners. Their methods have generally evolved over time, moving from an essentially qualitative to a semi-quantitative approach. At present, all are based on API standards 580 and 581 but these have been adapted according to the requirements and practices of the various petroleum groups and regulatory stipulations. They include the directives of UIC/UFIP guideline DT84 for drawing up an inspection plan to define the type and frequeny of periodic inspections and requalifications that may exceed five and ten years.

Although based on common reference documents, applications of the RBI approach by the various petroleum groups each show their own specificities at various stages in the approach.

For example, when defining failure modes, each group has established its own list, which generally comprises 50 to 60 modes, based on various guidelines (API 571, API 580, API 581, EFC guide, DT 32 & 84, etc.) and on its own expertise. Failure mode identification can be performed by:

- A refinery corrosion expert based on its corrosion manual, after first defining the various iso-degradation loops, or by
- The Inspection Department using software that will propose the various degradation mechanisms according to the equipment description (in this case, the corrosion experts work further upline, at the tool development level, to define the generic modes assigned to the various units),

Once the degradation mechanisms have been defined, the refineries may also have different approaches to determining equipment criticality. Some assess the consequences by failure mode (the extent of the failure is defined depending on the mode) so as to establish coefficients that will be weighted to evaluate the overall level of consequences on the equipment. Others assign a single level of consequences that will be based on the equipment inventory. In the latter case, the level of consequences is therefore intrinsic to the equipment (regardless of the failure mode).

Regarding the definition of the level of consequences, the facilities visited generally include safety, economic (essentially based on downtime) and environmental factors, with different weighting factors and these factors may vary from one group to another. In the same way, some prefer a risk matrix by type of consequence while others prefer a single matrix.

Regarding the consequences in terms of safety, it should be noted that all are inspired by the method set out in API 581, more or less adapted using the UFIP blue guide, results from hazard studies, etc.

Regarding the probability evaluation, the observations are fairly similar. The methods applied at the various facilities visited were all obtained from common reference databases (API and DT 84) and are based on semi-quantitative criteria. These criteria may however differ from one facility to another, as may their weighting rules. Feedback at each site may also cause evaluation methods to evolve.

Once the level of consequences and of probabilities has been evaluated, the criticality of the equipment is defined. Depending on the facilities, this results in 4 or 5 risk levels to which actions are assigned (as defined according to in-house rules) that are reused in the inspection plans. For example, for a certain level of risk, this may be combined with a visual inspection of x% of special points along the pipe, the removal of insulation from x% of those areas likely to be affected by CUI or to perform checks, etc. Generally, these actions depend on the failure modes that may affect the equipment.

Given the above mentioned elements, clearly the level of criticality defined for facilities that belong to different groups cannot be compared, even if the matrixes are of the same size (generally 5x5). Some feel that the most important element is how the result of any scoring is handled and not the score itself.

Furthermore, some of the facilities we visited regretted not being able to push the RBI approach further. This is because even if some equipment is not considered as critical in the RBI method (e.g. a compressed air tank, a piece of equipment that is only slightly exposed to failure modes, etc.), pressure vessel regulations impose monitoring constraints. As a result, after a metal shutdown, the regulatory deadlines (PI/PR) require operators to inspect hundreds of pressure vessels whereas they feel it would be desirable to undertake more targeted and more in-depth inspections on the few dozen most critical pressure vessels and to adopt a more corrective approach to the others. In other words they wish to better deploy inspection resources. Often the results of the RBI analysis and feedback developed by RID are confirmed. Less critical equipment that is not affected by failure modes are still inspected and the results simply confirm the absence of any anomaly.
Regarding the commercially available RBI analysis software, a number of refineries are hesitant as to its benefit. The advantage to be gained from the relevance of their analysis does not seem obvious to them. For these refineries, the RBI approach mainly revolves around reflection on equipment, the identification of degradation mechanisms, etc. The expertise gained by inspectors and feedback from them that is necessary for this thought process cannot be replaced by software. On the other hand they agree that this software can offer more in terms of ease of use or time savings. Often the facilities visited have developed their own tools (whether locally or at the group level) so as to perform their RBI analysis or to report and use non-destructive testing results.

2.3 Non-Destructive Tests

Non-destructive tests are for the most part performed by specialist contractors on medium term contracts (3-5 years). The RIDs are generally involved in the choice of the contractor. Regularly, the refineries perform audits to ensure that the HS rules are complied with on the worksite, that the measurement equipment is calibrated, that work instructions are complied with… Staff from these outside contractors are COFREND certified (with some refineries requiring this certification even when it is not mandatory). Often inspectors from outside contractors are present on-site full time.

After inspection, the inspectors submit their validated report to the RID. Some refineries require the inspectors to fill in the data entry forms in the software used to process the results (thickness measurements). In all cases, the results of the non-destructive tests are processed by the RIDs.

RID inspectors perform very few non-destructive tests.

The number of non-destructive tests is tending to increase. They are generally very numerous when preparing for major shutdowns.

Ultrasonic and X-ray test methods are often used. However, depending on the facility, radio usage is more or less widespread. Some restrict their use to confirming an anomaly detected, essentially on small diameter branches (DN ≤ 2''), others use them more widely, especially for pipe thickness measurements up to 8" diameters). Some refineries perform up to 10,000 a year.

Overall, RIDs are cautious as regards new non-destructive test methods and some only apply them after validation by the group head office.

To check the condition of tank bases, many use acoustic emissions and the SLOFEC method for performing a complete tank base scan and viewing the condition of both sides of the steel.

2.4 Handling Feedback

Generally, feedback from inspection departments is organised at various levels in the refineries visited:

- ***At the local level***
  The RID monitors containment failures (reportable leaks caused by corrosion excluding seals, pressure seals, etc.). Such failures vary in number from facility to another, ranging from around 10 to close to 70 a year. This difference can certainly be explained by the number of pressure vessels monitored and the various policies implemented for hazard prevention, but probably also by more or less rigorous reporting systems. In some cases, monitoring is detailed by the type of failure causing the containment loss and/or by the type of equipment. Piping is most frequently at fault. More or less detailed indicators have been set up covering the quantities released, the type of product, etc.
  Some mention references to instructive accident reports on forms intended for the inspectors so as to alert them to a specific point (inspection report).

- ***At the group level***
  Groups generally consolidate facility data and run statistical analyses on them. Some produce datasheets for accidents that provide lessons to be learnt and these may be distributed to all of the group's inspection departments, possibly on a graduated basis (one level of information and one level of action to be performed with a feedback report to the group level after action).

- ***At the professional level***
  The RIDs at the refineries visited take part in professional days so as to benefit from wider feedback (half yearly GEMER meeting, CTNIIC days held by UIC).

Most of the facilities visited have recently initiated action to improve the way feedback is handled: changes to quality and quantity indicators, tools for raising operator awareness, more in-depth analysis, etc.

On the other hand, anomalies observed during inspections that did not lead to containment failures remain recorded in the equipment history. These are not consolidated in a feedback database.

Furthermore, it appears that feedback from inspection departments that often provides lessons to be learnt (causes of a loss of containment, characterisation of the breakage, inventory of releases, actions undertaken, etc.) is seldom taken into consideration in the safety reports.

2.5 On-site and Off-site Piping

Impacts of the Act of 15 March 2000

The most critical piping at facilities has been monitored for many years now, however the Act of 15 March 2000 has nevertheless considerably increased the number of inspection plans.

Off-site, LPG lines were also monitored prior to 2000 and had their own inspection plan. Often, they were not actually subject to the new regulations, only to PI as their PS.DN rating does not exceed 3,500. The number of off-site pipes subject to PR is generally low and restricted to certain light petrol cuts with a saturating steam pressure of over 0.5 bars.

Before producing inspection plans, refineries generally have to commit to a major amount of work in terms of piping descriptions. Any knowledge of piping characteristics is mainly based on the construction standards used. Overall, data is less accurate and less readily available than for storage vessels. Furthermore, often there are no isometric drawings for off-site piping. Significant resources have therefore been mobilised to identify piping and its design.

A number of the facilities visited appear to adopt a specific approach for producing off-site piping inspection plans. Apparently, the plans are not specific to one line are established on a case-by-case basis (where all of the piping in the same set of pipe runs will be inspected in the same way: same type of inspection and frequency…). Consequently, the same line may be monitored by a number of inspection plans if it joins a number of runs. Only the most critical lines retain their own inspection plan (for LPG especially).

Applying the RBI approach to piping

Within the units, any evaluation of the level of consequences caused by piping issues is generally based on the assessment of the upstream capacity or on a weighting of the up and downstream capacity levels.

For off-site piping, the RBI approach is not always applied. Some feel that it is necessary to adapt their method so as especially to take better account of the environmental consequences and better determine the risk level hierarchy for the various pipes. This is because directly applying the method used in the units may lead to assessing a constant degree of risk for most of the off-site piping (with operating parameters that are often similar, unlike for units) and failing to sufficiently allow for the environmental factor where it may often be the most significant factor for off-site piping (e.g. heavy product lines close to property lines).

Feedback integration

Overall it appears that the kind of corrosion most often to blame for any loss of containment is corrosion under the insulation. Some of the refineries visited have therefore committed to major multi-year systematic inspection programs. These result in a visual inspection of all of the piping even in those areas that are hard to access such as racks, with special attention being paid to specific points and areas that may encourage this kind of corrosion (e.g. supports, low points, areas where the insulation is damaged). In some cases, complete insulation removal is performed. These programs make it possible to observe an initial state and result in updating of the inspection plans.

For off-site piping, some programs also include actions to clear pipeways so as to prevent degradation and facilitate inspection (removal of sand, weeds, clutter, scrapping unused lines, limiting or eliminating passages through ducts, etc.).

Given the lower severity of the operating parameters for off-site piping compared with that at units (P & T especially), the degree of outside corrosion in containment losses is even greater for off-site piping.

Remaining service life

None of the refineries visited sets an age limit for piping. On the other hand, they all regularly monitor pipe thickness to determine a remaining service life for time-dependent degradation mechanisms (corrosion, erosion, etc.).

For non-temporal mechanisms such as cracking, this notion is not used.

Thickness measurements performed essentially by ultrasonics (US) or radiographic examinations are used to assess the corrosion rate. This rate which can be calculated in different ways (between the first and the last measurement, between the last two measurements, from trends, etc.), can be used to estimate piping thickness during a given time interval or to give a forecast deadline for reaching a given thickness (scrapping thickness, replacement thickness, alert thickness, etc.). As a result, it is possible to estimate a remaining service life, generally used by the refineries visited to schedule the next inspection deadline. It should be noted that this service life estimation may differ between facilities, as they take into account varying safety margins, for example, that may sometimes be modulated according to the degree of piping criticality. Nevertheless, it appears that for the most part, the remaining service lives are greater than the regulatory inspection intervals (periodic inspection/periodic requalification). Consequently, the theoretical inspection deadlines estimated from the remaining service lives are capped by regulatory deadlines.

Generally the corrosion rates observed are less than the theoretical rates published in various reference works such as API 581, which are reputed to be conservative in nature. Some of the refineries visited have implemented a comparison of these values. If the measured rate exceeds the theoretical rate, then they trigger an investigation to identify the cause of this anomaly and take suitable measures, even if the remaining service life is acceptable.

Furthermore, some refineries increasingly anticipate thickness inspections ahead of shutdowns, so as to improve the scheduling of the necessary maintenance work and thereby attempt to reduce downtime. This practice does however lead to a misalignment with regulation inspection intervals.

Shutdowns that are planned for process purposes (non-regulatory requirements) are also used increasingly to perform non-destructive testing. Additionally, during unscheduled shutdowns, some refineries estimate the forecast restart date so as to perform non-destructive testing or to handle some of the inspection requests made by the maintenance department, if downtime allows this.

Lastly, for some piping components, like expansion compensators, the remaining service life cannot be estimated. Given their design, they tend to be very hard to inspect in operation. Some refineries proceed with expansion checks based on temperature variations. Others proceed with inter-wave visual inspections after disassembly but this operation may induce new stresses on the compensator after reassembly. Lastly, some refineries have started to think in terms of a possible systematic replacement approach after a set operating period.

2.6 Storage Tanks

Generally, all of the operators visited use a method that is close to the UFIP 2000 method. At the refineries, the inspectors who apply the inspection programs are generally atmospheric tank specialists. Tanks are complex and involve a large number of operators. The inspection departments coordinate operations between the various external contractors, the maintenance department and the operators.

Feedback:

Generally, feedback highlights the many failures affecting floating tank tops often with minor consequences and incidences of corrosion around the shell that may cause events ranging from a simple leak to complete tank rupture.

On the whole, operators record the following degradation mechanisms:

- Internal corrosion at the tank bottom, generally occasional and with the greatest chance of causing a leak. This is most frequent on crude oil tanks,
- External corrosion on annular plate and the tank bottom,
- Corrosion affecting the shell-bottom weld,
- Corrosion on both sides of the floating roof,
- Leaks in the tank top drains,
- Leaks in the floating roof seals,
- Cracks caused by slow fatigue affecting floating roofs.

Other mechanisms that are specific to each site may be encountered. For example, facilities located on unstable ground involve overall deformation affecting the shell and tank bottom.

Operator rounds:

These comprise visual inspection of certain sensitive points on the basis of a check-list. The check-lists are adapted by the RIDs according to facility issues, feedback and facility priorities. Initially, these lists are generally based on those set out in UFIP 2000, API 653 and/or EEMUA 159.

There is no set inspection frequency. The interval between two rounds may vary from one month to three years.

This check does not always lead to a report. Nevertheless, the operator is always required to report any anomaly found to the Inspection Department.

External inspection:

External inspection comprises a visual inspection of the tank shell, the breather systems, the tank top and its accessories, by a specialist inspector. During this inspection, some operators perform non-destructive testing, e.g. ultrasonic measurements of the tank shell, geometric settling measurements, roundness and vertical alignment measurements.

These checks are adapted to site conditions and equipment. In particular, tank settling checks are often related to terrain characteristics, as the land will vary in firmness from one site to another.

Depending on the operators, the external visual examination is performed every three to five years. This inspection generally involves non-destructive testing in addition to a visual examination. Nevertheless, these non-destructive tests may be performed regularly or they may take place on an exceptional basis (e.g. based on visually discovered anomaly). The inspection frequency also varies with the overall tank condition. For example, an accessory that is known to fail frequently will be inspected more often.

Leak detection using acoustic emissions:

All of the operators perform acoustic emissions tests to delay tank opening as much as possible. This check consists of using instruments to "listen" to the noise of active corrosion and/or leaks (see 4.1.2.1.5 in the report that is specific to refinery tanks). This method draws upon two parameters:

- The overall noise level due to generalised corrosion so as to determine the general corrosion level. This is represented by a letter from A to E.
- The localised signal intensity caused by corrosion peaks or leaks, so as to highlight a peak tank corrosion/leak level. This is represented by a number from 1 to 5.

The way the results are interpreted is specific to each facility. UFIP 2000 provides a matrix which serves as a basis for operators. Operators have sometimes however developed their own matrixes.

Although inspections must by law be undertaken every ten years, some operators perform these inspections at shorter intervals. These additional inspections are triggered by the results of previous acoustic emission checks. The use of these results increases the frequency of the acoustic emission checks and/or leads to closer monitoring until the tank is opened up.

This check is not seen the same way by all operators. For some, this is a relevant method for validating tank bottom integrity, whereas for others it is a method whose results must be interpreted with care. The reservations expressed by some operators result in part from implementation difficulties leading to significant variability in the measurements as well as from results that are sometimes hard to interpret.

Leak detection using external or internal measurements:

Some operators perform additional measurements so as to check for leaks. Mention was especially made of piezometer checks as well as internal soundings by measuring changes in level.

Tank opening:

When the tank is opened, the inspectors at operating facilities schedule a series of checks. It is normal usage to perform checks on the tank bottom thickness:

- On an occasional basis, based on a visual inspection of the tank bottom.
- On an overall basis, by mapping the bottom of the tank. Electromagnetic methods (MFL, SLOFEC) are used to perform this mapping in approximately two weeks.

The latter option is now “near systematic” for the operators queried. The SLOFEC method in theory allows both sides of the tank bottom to be checked.

At present, destructive checks for inspecting the outside of the tank bottom have been abandoned by all of the operators met, given the existence of the above mentioned methods.

Welds, especially the shell-bottom weld, are checked using ACFM or an equivalent method.

All of the accessories are inspected.

Opening up a tank allows repairs (if there are anomalies) and preventive maintenance to be performed.

Depending on the operators, these openings may take place at:

- Maximum intervals set by the operator,
- Intervals that depend on the results of the last acoustic emissions test and on leak monitoring.

Other parameters affect the interval between two openings:

- The way the tanks are managed commercially. The idea is to spread out periods of unavailability so as to avoid a decrease in the storage volume available and therefore any drop in production and the related operating losses,
- Customs regulations require finished product tanks to be opened for recalibration every ten years. This opportunity is often used by operators to perform all of the inspections and maintenance work required,
- In order to achieve a high level of finished product quality, some operators open up their tanks more often for cleaning,
- Performing additional checks makes it possible to keep the tank in service for longer without opening it up or withdrawing it from service.

The average service period between two openings appears to be between 15 and 20 years.

Remaining service life:

Manufacturers do not make atmospheric pressure tanks with a preset service life. Although a theoretical calculation formula exists, practice shows that many factors mean that this calculation is purely formal:

- Theoretical degradation rates may be far different from reality, with numerous factors influencing these theoretical rates,
- Localised degradation generally follows a progression rate that is faster than that of the known progression rules,
- A number of degradation mechanisms are not time-related but related to operating conditions,
- Maintaining faulty elements (e.g. tank bottom steel sheets) makes it possible to considerably modify the estimated service life.

The remaining service life is therefore defined by the period during which the tank base and skirt integrity is maintained. This calculation is based on corrosion rates that may be calculated in various ways (between the first and the last measurement, between the last two measurements, from trends, etc.). The corrosion rate as calculated may be different for the bottom and the skirt. The different rates are used to obtain a maximum duration before the thickness of one of the metal sheets falls below the design thicknesses taken from conventional building codes (CODRES, BS 2654, API 620/650, etc.).

Repairs and preventive maintenance:

In terms of tank repairs, some conventional maintenance actions are common to all of the operators we met. As an example, the following conventional points can be mentioned:

- Steel sheets with few corrosion points are reloaded,
- Steel sheets with a multitude of corrosion points or significant generalised corrosion are replaced,
- Tank bottoms that show too much generalised corrosion are replaced.
- Faulty seals (around floating tops or screens) are replaced.

The opening of a tank also offers the opportunity for maintenance teams to perform preventive work.

Preventive maintenance is an integral part of the tank management policy. As such, the methods set out vary from one operator to another. Some operators for instance apply an epoxy coating on the tank bottom when the tanks are opened whereas others remain more reserved as to this preventive action.

The major advantage of an epoxy coating as mentioned by operators is that it practically eliminates internal corrosion affecting coated areas (generally the bottom and the annular plate). The drawbacks mentioned by some operators are justified by difficulties in properly applying the coatings which may lead to coating defects such as, for example, corrosion traps.

Prospects:

Some operators are currently implementing an RBI or similar method for inspecting atmospheric pressure tanks. These methods are to date still in the design or test phase, or at best in a progressive application phase. To date, none of the installations visited applies the RBI method to all of their atmospheric tanks.

For example, tanks may be split into a number of different entities (i.e. the foundations/bottom, the hoop/bottom and hoop/top). Each of these areas would be treated separately, depending on the conception and on the product stored. Degradation mechanisms will be determined, then the consequences and probabilities assigned to each mechanism will be defined to obtain a degree of criticality. Inspection and maintenance will then be adapted to suit this degree of criticality.

2.7 Structures and Civil Works

Monitoring and managing repairs and modifications:

Unlike existing practices in other fields, civil engineering aspects are not covered by systematic inspections. The flaws are for the most part detected visually during routine rounds performed by an unspecialised operator. They are then sent to the company's civil engineering department when the company has one. A specialist is then called upon to conduct a survey before starting any work.

Nevertheless, the refineries visited have committed to inspection actions covering civil engineering structures and works (pipe rack, column skirts, gangways, flare derricks, gutters, containment dykes, sphere supports, etc.). These actions are recent however and primarily aim to establish a baseline.

Service life, degradation mechanisms and detection techniques:

- **<u>Containment dykes</u>**:
    - Most of the containment dykes encountered consist of concrete walls or containment tanks made from clay-sand materials.
    - Some companies have performed the following operations: replacement of sheeting piles with concrete walls.
    - Sealing tank bottoms with a polyethylene film sandwiched between two geotextile layers and covered with reinforced concrete.
    - During the 2008 inspection campaign, 25% of the containment dykes inspected showed serious degradation or cracking affecting the coating or the material constituting the containment.
    - A cost-effective way to check for leaks is to check the water level after rain, some companies perform this check every year.
    - In design terms, 25% of containment dykes are undersized. It is also extremely frequent for there to be no supporting evidence, in design terms, of the ability of the structures to resist a wave effect.

- **Pipe racks**:

  Some companies have started inspection campaigns (baseline for pipe racks and inspection policies) expanded to cover infrastructure supports. When any monitoring of pipe support foundation blocks is performed, visual inspection is carried out.

- **Tank foundations, liquid networks under foundations**:

  Regular visual inspection actions are performed on the fire break siphons at some of the facilities so as to ensure that the collection networks are sealed (checking that the network is under pressure). Sometimes, more extensive checks are performed (pressurising and performing a density check over a given time interval, running a camera investigation if an anomaly is detected, etc.). Where pipes pass under roads or through bund walls, presenting an increased risk of external corrosion or causing hindrance during inspection, modifications are envisaged or performed at a number of facilities (building overpasses, running the piping over the traffic lanes, rebuilding the ducts, replacing the tank dyke with a concrete wall to provide containment outlets, etc.).

- **Others**: Sphere supports, etc.

  In cases of confirmed or suspected damage, some refineries run non-destructive tests on the metal structure (US thickness tests), after first removing the fireproofing. For column skirts, it is not always necessary to destroy the fireproofing as some non-destructive testing can be performed without doing so (using eddy currents).

2.8 Instrumentation

Digital command and control systems

Generally the digital command and control systems are reliable. Given their design, failures often have no impact on unit operation. Refineries monitor failure rates. This parameter is taken into consideration when envisaging any change of technology. Other parameters are also taken into consideration such as:

- The availability and supply of spare parts,
- The validity of vendor support,
- Increased maintenance costs,
- Maintaining staff skills,
- etc.

System vendors offer variable forms of support over time:

- During an initial period (generally 10 to 20 years for digital command and control systems) together with a guarantee for spare parts and lead-times,
- An additional guaranteed maintenance period of 3 to 6 years. During this period, the supplier makes a commitment regarding the supply of parts and their availability lead-times.
- A so-called extended contract period during which the spare part delivery lead-time is no longer guaranteed.

As refineries do not define a set service life for their systems, any replacement is primarily dictated by the sustainable availability of skills and spare parts.

SIS

For a number of years now, refineries have been replacing their relay-based safety systems with failsafe PLCs. Increasingly, these systems make reference to operating security standards (IEC 61508 and IEC 61511 standards) to define a safety level (SIL).

Some refineries have kicked off specific SIS plans to assess the systems already in place (suitable architecture, system capacity to detect problems, type and frequency of tests, compatibility with the required SIL level…) and how to replace them when necessary and to choose suitable equipment for new systems.

The tests are generally scheduled by the instrumentation departments and then entrusted to specialist external contractors. Special attention is paid to the skills of the contractors chosen to perform the tests but there is not necessarily any formal approval process.

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Parc Technologique Alata
BP 2 - 60550 Verneuil-en-Halatte

Tél. : +33 (0)3 44 55 66 77 - Fax : +33 (0)3 44 55 66 99

E-mail : ineris@ineris.fr - **Internet :** http://www.ineris.fr